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Analyses of Potential Ravine and Bluff Stabilization Sites within the Blue Earth and Le Sueur River Basins

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Endorsement Date: _______________________

This thesis, completed by Anna My-Tien T. Tran, has been examined and approved by the following members of the student's committee.

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Abstract

Analyses of potential ravine and bluff stabilization sites
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The United States Environmental Protection Agency (USEPA) has listed much of the Upper Mississippi River (UMR) basin as impaired waters due to excessive turbidity, sedimentation, and nutrient loading. Of particular importance are the associated environmental problems (e.g. eutrophication, habitat and wetland loss, loss of biodiversity, and changes in water quality) that have developed within Lake Pepin, a popular recreational riverine lake of the UMR. Three major drainages contribute to these issues and empty in to the UMR near Lake Pepin - the Minnesota River Basin (MRB), St. Croix River, and UMR.

The MRB makes up approximately one-third of the drainage area above Lake Pepin, but has been found to contribute approximately 85-90% of all sediment entering the lake – both in the past and present. A major tributary system of the MRB, the Blue Earth River Basin (BERB) and its subbasins, contribute as much as half of the sediment exiting the Minnesota River, despite accounting for only one-fifth of the MRB drainage area. The tremendous sediment yields from this basin are a result of both post-glacial landscape evolution and contemporary land-use practices. Recent radioisotopic fingerprinting of these sediments has helped narrow the focus of mitigations strategies

as they indicate that the majority of the sediment originates from near-channel sources in the MRB, specifically ravines and bluffs. Significantly, it was also found that the rate of sedimentation has increased ten-fold over the past 150 years. Thus, mitigations strategies to curtail the sediment yields arriving downstream should focus on the near-channel sources of the BERB and its subbasins.

Unfortunately, the resolution of radioisotopic methods is inadequate in locating of specific near-channel sources on which to implement mitigation strategies. Therefore, a crucial first step of an effective mitigation strategy to reduce erosion is to develop a methodology that aids in identifying the precise geographic position of ravines and bluffs with high erosion potential.

This study uses Geographic Information Systems (GIS) to compile county Light Detection and Ranging (LiDar) and elevation, watershed and stream network, county infrastructure (private and public buildings and roads), county and watershed soil, county and watershed land use data in the BERB and its subbasins, to attempt to locate precise locations of ravines and bluffs with high erosion potential. Using two LiDar data sets taken in 2005 and 2012, and incorporating net sediment loss, slope grade, soil material, soil texture, connectivity to river, distance to river, surrounding adjacent land use, proximity and threat to roads, proximity and threat to public and private buildings, accessibility from roads, visibility from stream, and visibility from roads; 14 ravines and 10 bluffs were identified in the BERB, and 18 ravines and 29 bluffs were identified in the BERB, the Le Sueur River Basin (LSRB). These ravine and bluff sites exhibited an

abundant amount of erosion between 2005 and 2012. As a baseline study, a comprehensive review of hydrologic and sediment transport models and stabilization techniques were completed to provide natural resource managers tools to stabilize and effectively manage these erosive sites.

Preliminarily, this thesis study provides an effective protocol for identifying potential mitigation/stabilization sites that are not readily accessible with conventional surveying equipment. The models and stabilization techniques reviewed are effective strategies for watershed management in highly geomorphically active regions. Moving forward, a future LiDar dataset is recommended for further temporal and spatial analysis of the identified sites. Moreover, long-term monitoring of selected sites are recommended in order to isolate parameters to model erosion events, determine rates of change, and further understand the evolution of the landscape for effective watershed management.

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Abbreviations

AGNPS	Agricultural Non-Point Source
AnnAGNPS	Annual Agricultural Non-Point Source
ANSWERS	Areal Nonpoint Source Watershed Environment Response Simulation
APEX	Agricultural Policy/Environmental eXtender
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BERB	Blue Earth River Basin
BMP	Best Management Practice
B.P	before present
c	circa
C	Carbon
cal	calendar
cm	centimeter
CN	Curve Number
CREAMS	Chemical Runoff and Erosion from Agricultural Management Systems
DEM	Digital Elevation Model
EGEM	Ephemeral Gully Erosion Model
EPIC	Environmental Policy Integrated Climate
FORTRAN	Formula Translating System
FREF	Fabric Reinforced Earth Fill
GIS	Geographic Information Systems
GPS	Global Positioning System
ha	hectare
HSPF	Hydrologic Simulation Program, Fortran
ka	kiloannum
km	kilometer
km^2	square-kilometer
LAS	Laser File Format
LiDar	Light Detection and Ranging
LIS	Laurentide Ice Sheet
LISEM	Limburg Soil Erosion Model
LSRB	Le Sueur River Basin
LWD	Large Woody Debris
m	meter
m^2	square meters
mm	millimeter
MNBWSR	Minnesota Board of Water and Soil Resources
MNDNR	Minnesota Department of Natural Resources
MNDOT	Minnesota Department of Transportation
MNGEO	Minnesota Geospatial Information Office
MPCA	Minnesota Pollution Control Agency

MRB Minnesota River Basin
MUSLE Modified Universal Soil Loss Equation
N Nitrogen
NAD North American Datum
NOx Nitric Oxide and Nitrogen Dioxide
NRCS National Resources Conservation Service
P Phosphorus
PCS Projected Coordinate System
PET Potential Evapotranspiration
PM2.5 Fine Particulate Matter smaller than 2.5 micrometers
PM10 Particulate Matter up to 10 micrometers in size
REGEM Revised Ephemeral Gully Erosion Model
RMSE Root Mean Square Error
RS Remote Sensing
RUSLE1 Revised Universal Soil Loss Equation 1
RUSLE2 Revised Universal Soil Loss Equation 2
SedNet Sediment River Network
SWAT Soil and Water Assessment Tool
t ton
TMDL Total Maximum Daily Load
TDS Total Dissolved Solids
ton tonnes
TSS Total Suspended Solids
UMR Upper Mississippi River
USA United States of America
USDA United States Department of Agriculture
USEPA United States Environmental Protection Agency
USGS United States Geological Survey
USLE Universal Soil Loss Equation
UTM Universal Transverse Mercator
WEPP Water Erosion Prediction Project
yr year

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Introduction

Landscapes disturbed by geomorphic and/or anthropogenic influences often induce spatially varied and highly localized changes in rates of erosion and sediment loading in to fluvial systems (Zimmerman et al., 2003; Engstrom, 2009a; Belmont et. al., 2011; Day et al., 2013b). In conjunction, resulting sediment loading and related increases in turbidity can result in impaired fluvial systems (Engstrom, 2009a; Wilcock, 2010; Hansen et al., 2010; Belmont et al., 2011; Gran et al., 2011; Gran et al., 2013; Gunderson et al., 2015; EPA, 2015b). The impact of fluvial system response to disturbance can result in a wide-ranging suite of related environmental issues exemplified by numerous studies published in the literature.

Biological impacts of fluvial adjustment include: loss of aquatic habitat (Waters, 1995; Zimmerman et al., 2003; Lenhart et al., 2011a; Lenhart et al., 2011b); loss of submerged vegetation (Uri, 2000; Arnell, 2002; Raven et al., 2008; Pennington and Cech, 2010); and decrease in fish populations (Waters, 1995; Zimmerman et al., 2003; Madej, 2004; Pennington and Cech, 2010; Lenhart et al., 2011a; Gunderson et al., 2015). Ecological impacts include: loss of wetlands (Raven et al., 2008); nutrient loadings and imbalances (Raven et al., 2008); increase in turbidity (Waters, 1995; Madej, 2004; Raven et al., 2008); and decrease in dissolved oxygen (Waters, 1995; Uri, 2000). Proper mitigation strategies must then understand and take into account the mechanisms of erosion and pinpoint areas susceptible to erosion in an impaired fluvial system; they are, however, exceedingly difficult to determine (MPCA, 2009; Wilcock, 2010; Belmont et al., 2011).

In recent years, the Upper Mississippi River (UMR), USA, and its subbasins, have been the emphasis of emergent research regarding environmental concerns due to nutrient and sediment loading in this system (Bauer et al., 2002; Sekely et al., 2002; Thoma et al., 2005; Engstrom, 2009a; Engstrom et al., 2009b, Gran et al., 2009; Lenhart et al., 2009; Mulla and Sekely, 2009; Hansen et al., 2010; Lenhart et al., 2010; Schottler et al., 2010; Wilcock, 2010; Belmont et al., 2011; Gran et al., 2011; Kessler et al., 2011; Lenhart et al., 2011a; Lenhart et al., 2011b; Lenhart, 2012a; Day et al., 2013a; Day et al., 2013b; Gran et al., 2013; Schottler et al., 2013; Gunderson et al., 2015). Much of this situation was set by the geomorphic history of the landscape (Knox, 1987; Knox, 1996; Gran et al., 2009; Hansen et al., 2010; Gran et al., 2011; Gran et al., 2013), but it has also been influenced by more recent anthropogenic influences - as European settlers dramatically altered land cover and usage through the conversion of prairie to agricultural fields (Knox, 1987; Knox, 2001; Engstrom et al., 2009b; Gran et al., 2009; MPCA, 2009; Mulla and Sekely, 2009; Hansen et al., 2010; Wilcock, 2010; Gran et al., 2011).

The transition from glaciation to present day conditions has resulted in dramatic adjustments of the fluvial system throughout the region (Knox, 1996). Many of these systems are still actively responding to regional incision in to the landscape as a result of proglacial outburst floods (Gran et al., 2013; Faulkner et al., in Press). As the Laurentide Ice Sheet (LIS) retreated from the mid-continent at the end of the last glaciation, meltwater from the wasting ice was impounded by a low moraine dam in western

Minnesota and formed glacial Lake Agassiz (Schottler et al., 2010; Gran et al., 2011; Gran et al., 2013). Roughly 13,400 cal B.P., glacial Lake Agassiz drained through the proto-Minnesota River, also known as Glacial River Warren, lowering the Minnesota River valley bottom by as much as 70 m (Knox, 1996; Fisher, 2004; Gran et al., 2009; MPCA, 2009; Wilcock, 2010; Schottler et al., 2010; Belmont et. al., 2011; Gran et al., 2011; Day et al., 2013b; Gran et al., 2013). The initial incision started knickpoints that migrated upstream on tributaries flowing into what is now known as the Minnesota River valley (Gran et al., 2009; Gran et al., 2011; Gran et al., 2013).

Prior to incision, the Blue Earth River Basin (BERB) and Le Sueur River Basin (LSRB), tributaries of the Minnesota River Basin (MRB), were likely low gradient streams of glacial meltwater origin (Gran et al., 2009; Schottler et al., 2010; Gran et al., 2011). In response to the formation of the Minnesota River valley and after the flows of River Warren had ceased, the tributaries draining into the Minnesota River valley incised in to the landscape and have been doing so for the last 13-14 thousand years. The ongoing incision results in a landscape primed for the high sediment yields like those flowing in to Mississippi River (Gran et al., 2009; Schottler et al., 2010; Gran et al., 2011; Gran et al., 2013).

Lake Pepin, an ~100 km^2 natural riverine lake situated on the Mississippi River, is an important recreational and commercial resource for the region (Engstrom et al., 2009b; Gran et al., 2009; Schottler et al., 2010). Located approximately 95 km south of St. Paul, Minnesota, Lake Pepin formed on the Mississippi River between the Minnesota and Wisconsin border upstream of the Chippewa River, which deposited its sediment load, damming the Mississippi River valley (Engstrom et al., 2009b; Gran et al., 2009; Mulla and Sekely, 2009; Schottler et al., 2010; Faulkner et al., in Press). Lake Pepin is nearly unique because it acts as an archival depositional basin, where sediments from the Mississippi River can accumulate conformably, allowing numerous studies to use paleolimnological methods to examine long-term environmental change in large fluvial systems, including the pre-settlement period so lacking in records from man-made reservoirs (Engstrom, 2009a; Engstrom et al., 2009b; Schottler et al., 2010). Over the past 150 years, however, the rate of sediment supply into Lake Pepin has increased ten-fold, from 79,000 t/yr before c. 1830 to 876,000 t/yr during the 1990s (Engstrom et al., 2009b; Gran et al., 2009; Mulla and Sekely, 2009; Schottler et al., 2010; Belmont et. al., 2011).

The sediment cores from Lake Pepin ascertained that the rate of sedimentation in the past decade has remained large, providing strong evidence from radioisotope fingerprinting that the dominant source of sediment load shifted from agricultural soil erosion to near-channel erosion (Schottler et al., 2010). Sediment sources of Lake Pepin derive from near-channel sources such as ravines eroding through incision, elongation, and mass wasting; bluffs eroding through mass wasting as a result of fluvial undercutting and sapping; and streambanks erosion from above and beyond the volume involved in floodplain exchange (Gran et al., 2009; Gran et al., 2013). A chemical analysis of the sediment indicated that 80-90% of the sediment originates from the

BERB and LSRB (Kelley and Nater, 2000b; Gran et al., 2009; Mulla and Sekely, 2009; Schottler et al., 2010; Belmont et al., 2011; Gran et al., 2011). Together, the BERB and LSRB contribute as much as half of the sediment entering the Minnesota River, even though they only account for one-fifth of the MRB's drainage area (Magner and Steffen, 2000; MPCA, 2009; Lenhart et al., 2010; Wilcock, 2010; Lenhart et al., 2011a; MNBWSR, 2011; MPCA, 2013).

Extrapolating present-day sediment accumulation rates, the remaining volume of Lake Pepin (553 x 10^6 m^3 in 1990) will be filled completely in approximately 340 years (Engstrom et al., 2009b; Gunderson et. al., 2015). Given the increased accumulation rates (3.0 cm $year^{-1}$), the shallow upper one-third of the lake will cease to be useful for recreational or commerce within approximately a century (Engstrom et al., 2009b). Without this accelerated accumulation of sediment loading, Lake Pepin would be on average 1 m deeper today, and could persists another 4,000 years (Engstrom et al., 2009b). Therefore, restoration of the MRB would also provide numerous economic and social benefits, yet serious constraints for resource management persists (Lenhart, 2012a).

Although the principal sources of sediment erosion originates from near-channel sources (Engstrom et al., 2009b; Lenhart et al., 2010; Belmont et al., 2011; Day et al., 2013b), the geographic position of erosive ravines and bluffs are obscure. In order to direct restoration efforts, a method of identifying critically erosive sites to determine an inventory of ravines and bluffs is crucial for water resource management (MPCA, 2009;

Belmont et al., 2011). The proposed method spatially analyzes existing multi-temporal Light Detection and Ranging (LiDar) data to determine sites that exhibit high levels of erosion, providing natural resource managers an effective tool to stabilize and manage watersheds. A comprehensive hydrologic and sediment loss model review allows natural resource managers to further understand the changes occurring in the study area, and allows them to make better informed decisions. Finally, this study reviews three alternative approaches to ravine and bluff stabilization, including techniques and impacts of each approach. Furthermore, this study aims to be a starting point for further discussion, it was intended to develop a safe and efficient method of identifying principal sediment sources, and to promote restoration concepts that may be studied and pursued in more detailed in the future.

Research Objectives

1: Using multi-temporal LiDar datasets to identify a complete inventory of ravines and bluffs within the BERB and LSRB.

2: Review of hydrological and sediment transport models to provide a foundation for natural resources management within watersheds.

3: Analyze costs and benefits of evaluated stabilization projects and review of potential stabilization techniques to employ in the management of natural resources.

Literature Review

Geomorphology of the Minnesota River Basin

The Minnesota River flows southeast from its source at Big Stone Lake in western Minnesota to Mankato, Minnesota. It then bends north to join the Mississippi River near St. Paul, Minnesota. At approximately 540 km long, the MRB drains nearly 20% of Minnesota, as well as portions of South Dakota, Iowa and North Dakota (MRBDC, 2011). The MRB covers 37 counties and ~43,400 km^2 making it the state's largest tributary to the Mississippi River – but also one of the most polluted rivers in the state (MRBDC, 2011). Rivers and streams within the MRB show high levels of turbidity, which impairs the ecosystems of the associated with the river, as well as downstream water bodies to which it drains (MPCA, 2009; Lenhart et al., 2010; Wilcock, 2010).

The geomorphic history of the MRB begins with the influence of the Pleistocene glaciations that once occupied the region (MPCA, 2009; Schottler et al., 2010; Wilcock, 2010; Gran et al., 2013). Episodic advance and retreat of glacial ice deposited enormous quantities of glacial sediment, burying the former landscape. During the last glacial maximum, the Wisconsinan, proglacial lakes of ponded meltwater formed along the southern margin of the LIS. The LIS started to retreat from the northern United States ~20,000 cal yr B.P., filling in the eroded areas that were carved during its advance with meltwater (Michalek, 2013). The largest of these proglacial lakes was glacial Lake Agassiz, which formed about 13,670 cal yr B.P., and drained completely about 8,480 cal yr B.P. (Clarke et al., 2004; Lepper et al., 2007; Michalek, 2013).

The history of Lake Agassiz can be divided into five main phases: Lockhart, Moorhead, Emerson, Nipigon, and Ojibway (Leverington et al., 2002; Michalek, 2013). The Lockhart Phase (13,670-12,740 cal yr B.P.) was a period when the southern outlet was an active spillway (Elson, 1967; Fenton et al., 1983; Leverington et al., 2002; Lepper et al., 2007; Michalek, 2013). The high flows of the southern outlet are referred to as Glacial River Warren, the predecessor to the modern Minnesota River. The Moorhead Phase was a low-water phase that occurred ~12,740-11,690 cal yr B.P. (Lepper et al., 2007; Michalek, 2013). During the Moorhead Phase, isostatic rebound and glacial readvance closed lower outlets and stabilized Lake Agassiz. Gradually lake level increased (Thorleifson, 1996; Leverington et al., 2002; Michalek, 2013). The Emerson Phase (11,690-10,630 cal yr B.P.) was characterized by fluctuating lake levels with multiple outlets becoming activated (Leverington et al., 2002; Michalek, 2013). Most overflow during the Emerson Phase was through the northwestern outlet, however, changes in ice configuration, isostatic rebound, and outlet erosion led to several short episodes of rejuvenated southward flow (Teller, 2001; Leverington et al., 2002; Michalek, 2013). The Nipigon Phase ensued from 10,630-9,160 cal yr B.P. (Michalek, 2013), this phase led to the final abandonment of the southern and northwestern outlets (Teller and Thorleifson, 1983; Leverington et al., 2002). The Ojibway Phase began when Lake Agassiz combined with glacial Lake Obijway (Leverington et al., 2002) around 9,160-8,480 cal yr B.P. (Michalek, 2013). Lake Agassiz-Ojibway drained through the Kinojevis outlet to the Ottawa River Valley until the LIS no longer provided a barrier to the northward outflow into the Tyrrell Sea (Leverington et al., 2002).

The initial drainage of the southern outlet of Lake Agassiz, during the Lockhart Phase (Knox, 1996; Fisher, 2004; Blumentritt et al., 2009; Gran et al., 2009; MPCA, 2009; Wilcock, 2010; Schottler et al., 2010; Belmont et. al., 2011; Gran et al., 2011; Day et al., 2013b; Gran et al., 2013) downcut in to the landscape by as much as 70 m (Knox, 1996; Fisher, 2004; Gran et al., 2009; MPCA, 2009; Wilcock, 2010; Schottler et al., 2010; Belmont et. al., 2011; Gran et al., 2011; Day et al., 2013b; Gran et al., 2013). This incision resulted in knickpoints that have been migrating upstream on tributaries since that time (Gran et al., 2009; Gran et al., 2011; Gran et al., 2013). Ongoing headward migration of knickpoints/knickzones in these tributaries contribute large amounts of sediment to the modern Minnesota River, from erodible glacial underlying the modern landscape (MPCA, 2009; Wilcock, 2010).

Blue Earth County, Minnesota is encompassed within the MRB and contains many rivers that are deeply incised with steep and unsteady banks. Blue Earth County has the most rivers of any county in Minnesota (Kessler et al., 2011); the major waterways include: the Blue Earth, the Le Sueur, Watonwan, Maple, Big Cobb and Little Cobb Rivers, and Perch Creek (Kessler et al., 2011). The Watonwan River and Perch Creek are tributaries of the Blue Earth River, and the Maple, Big Cobb and Little Cobb Rivers are tributaries of the Le Sueur River (MPCA, 2009; Kessler et al., 2011; MPCA, 2015).

The BERB is approximately 4014 km^2, of which, 3139 km^2 are located in Minnesota, the rest in Iowa (GBERBA, 2009). The Blue Earth River begins in northern Iowa and converges with the West Branch Blue Earth River in Faribault, and from there, flows 173 km northward into Mankato where it converges with the Minnesota River (GBERBA, 2009). The total length of streams in the BERB is 1896 km, which includes its tributaries, public and private drainage systems, lakes, and wetlands (MRBDC, 1999). The BERB is characterized by a terrain of gently rolling prairie and glacial moraine with river valleys and ravines cut into the landscape (Bauer et al., 2002; GBERBA, 2010).

The oldest and deepest rocks of the BERB are Precambrian in age, found primarily in the western third of the watershed (MPCA, 2013). These rocks are hard and relatively impermeable crystalline rocks that are of igneous and metamorphic origin (MPCA, 2013). To the west of the Precambrian rocks are the primary bedrock, Cambrian then Ordovician sedimentary rocks that lie in a west to east gradient through the remaining two thirds of the watershed (MPCA, 2013). Pleistocene glacial deposits cover the majority of the watershed, and primarily compose of till and unstratified moisture of clay, sand, silt, and gravel (MPCA, 2013). At the center of the watershed, a flat lying thin clay deposit is present on top of the till, a remnant lake bed of “glacial” Lake Minnesota (MPCA, 2013). Buried bedrock throughout the valley are evidence of preglacial drainage patterns, these valleys were later filled by glacial deposits during the glacial advances mentioned above (MPCA, 2013).

The LSRB is approximately 2880 km^2, with approximately 1933 km of intermittent streams (MRBDC, 2015). The Le Sueur River flows north and west from Freeborn County and converges with the Blue Earth River before it joins the Minnesota River at Mankato (MPCA, 2009; Kessler et al., 2011). The landscape and terrain of the LSRB is highly variable, from sharply dropping hills in the southeastern edge to gently rolling hills in the northwestern portion (MPCA, 2015).

The LSRB is generally characterized by thick clayey glacial drift (MPCA, 2012a). Glacial sediments in the LSRB generally range from 30-60 m in thickness. The western half of the watershed is dominated by a relatively flat area composed of silt and clay deposits, which are remnants of glacial events mentioned above (MPCA, 2012a). Surrounding the glacial lake sediments to the west and north are ground moraine and stagnation moraine deposits, composed of rolling hills of unstratified till (clay, sand, silt) (MPCA, 2012a). Glacial sediments are underlain in the eastern two thirds of the watershed by sandstone and limestone aquifers, moreover, crystalline bedrock underlies the watershed in the western third (MPCA, 2012a).

Instability, from natural knickpoint migration were found throughout tributaries in both watersheds, making the landscape prime for erosion (MPCA, 2012b). Specifically, this incision was experienced by the Le Sueur, the knickpoint spread 40 km up the Le Sueur River network, leading to a rapid vertical incisions (~5 m/ka) producing valleys with steep river gradients (0.002 m/m) actively eroding bluffs and ravines (Gran et al., 2009; Belmont et al., 2011; Gran et al., 2011). In the geological time scale, both the BERB and LSRB are relatively young watersheds that are actively eroding and adjusting to the landscape (MPCA, 2012b). Therefore, ravine and bluff erosion, driven by hydrology and sediment transport, continues today through fine-grained till substrate (Gran et al., 2009; Gran et al., 2011; Gran et al., 2013).

Erosion and Sediment Sources in the MRB

The most prominent sources of sediment contribution to the MRB in the BERB and LSRB can be grouped into four broad point sources: fields, ravines, bluffs, and stream banks (Sekeley et al., 2002; Thoma et al., 2005; Wilson et al., 2008; Juracek and Ziegler, 2009; MPCA, 2009; Schottler et al., 2010; Wilcock, 2010; Belmont et al., 2011; Zaimes and Schultz, 2012). The research in this thesis focuses primarily on ravine and bluff erosion. Although there is no current data quantifying ravine erosion, it is important to note that ravines erode by a combination of hillslope and fluvial processes, and the primary driver of erosion is discharge to the ravine, which can be increased by upland drainage system alterations (MPCA, 2009; Wilcock, 2010). Bluff erosion is the result of three primary mechanisms: undercutting, sapping, and weathering (freeze-thaw cycles) (MPCA, 2014; Gunderson et al., 2015). Bluff erosion is driven by river erosion at the toe which triggers slope failure by grain fall, slumping, gullying and block fall (MPCA, 2009; Wilcock, 2010; Gran et al., 2013; Gunderson et al., 2015).

Rates of erosion for both the BERB and LSRB since European settlement in the late 1800s has increased many times over (Engstrom et al., 2009b; Gran et al., 2009; Gran et al., 2011; Gunderson et al., 2015). This increase in erosion can be attributed to changes in climate, and land use such as the conversion of native prairie to the development of row-crop agriculture throughout the watersheds (Kelley and Nater, 2000a; Gran et al., 2009; MPCA, 2009; Mulla and Sekely, 2009; Wilcock, 2010; Gran et al., 2011).

Contributing Factors of Increased Discharge, Surface Runoff, and Sedimentation

Due to glacial activity and instability from knickpoint migration, the MRB is naturally primed for erosion, however, anthropogenic influence detrimentally affect the hydrology and sediment erosion. Factors contributing to increased discharge, surface runoff and sedimentation include global climate change, in terms of rising global surface temperatures; and land use changes, in terms of land conversion and use changes.

Increased annual precipitation has been found throughout the state of Minnesota, the increase is augmented by frequent and intense precipitation events (Seeley, 2003; Novotny and Stefan, 2006). Precipitation totals of 7-day period exceeding a 1-yr recurrence interval has increased in frequency throughout the state of Minnesota from 1931 to 1996 (Kunkel et al., 1999). Douglas et al. (2000) found upward trends in low flows in the upper Midwest regions which include Minnesota. A comprehensive basin by basin study of the state of Minnesota conducted by Novotny and Stefan (2006) determined that peak flows due to rainfall are increasing in the MRB and Mississippi River Basin, which would coincide with the increases of more frequent and heavy rain events in Minnesota and the USA (Karl and Knight, 1998; Seeley, 2003).

Increasing global temperatures also shift the ice in and ice out dates. A previous study of hydrological data from Minnesota found trends in five water resource parameters that reflect climate warming over the past 25 and 40 years (Johnson and Stefan, 2006). Ice-out dates on lakes are occurring earlier in the spring season, stream waters were found to be rising, and thus ice in dates were found to occur later in the year (Johnson and Stefan, 2006). This study also found that the first spring runoff and the first spring peak runoff in the state of Minnesota have occurred on average 0.3 days/yr earlier during 1964-2000 (Johnson and Stefan, 2006). A direct correlation to the ice in and ice out dates were found with changes in air temperatures for these parameters (Johnson and Stefan, 2006).

Post-European settlement conversions in the MRB of native forests and prairie grasslands to accommodate agriculture, urbanization, and industrialization are closely related to the increases in total sediment load (Kelley and Nater, 2000a; Gerla, 2007; Mao and Cherkauer, 2008; Lenhart et al., 2012b). Twine et al. (2004) conducted simulations using the Integrated Biosphere Simulator land surface/ecosystem model on the MRB, and found that reductions in evapotranspiration leads to increases in total runoff as a result of forest conversion to cropland, and runoff decreases in response to conversion of grassland to crops. Mao and Cherkauer (2008) determined that in the Midwest, USA, deforestation of deciduous forests have resulted in a 5-15% decrease in evapotranspiration and a 10-30% increase in total runoff, moreover, conversion from prairie grassland to row agriculture crop resulted in a 10-15% increase in evapotranspiration and a 20-30% decrease in total runoff. Although many studies have evaluated the effect of deforestation on runoff, insufficient quantifiable data representing the changes for grassland to cropland conversion exists (Gerla, 2007). The effect on sediment contributions from each tributary to Lake Pepin, however, may be influenced by the presence of locks and dams on various locations on the rivers, as well as dependent upon the exact form of land cover conversion (Twine et al., 2004).

To improve agricultural yields, vast areas of Minnesota have been drained by installing drainage networks to efficiently remove water (Houser and Richardson, 2010). In recent decades, rates of channel erosion have been exacerbated by the extensive use of agricultural tile drainages and land cover changes that have contributed to increased streamflow in many southern Minnesota streams (Lenhart et al., 2012b; Schottler et al., 2013). Knox (2001) studied agricultural influence on landscape sensitivity in watersheds of the UMR and found that the conversion from natural vegetation to agricultural land use has increased the frequency of large floods. Kelley and Nater (2000a) states that increases are assumed to be from the gradual modification of the 92% surface area in the MRB, through the use of ditching, installation of subsurface tile lines, loss of wetlands and riparian zones, and loss of native prairie to support agricultural production, primarily row crops. Anthropogenic alterations to land use and surface cover in the watersheds may have contributed to increasing stream flows throughout the state of Minnesota (Kelley and Nater, 2000a), however, Novotny and Stefan (2006) states that additional studies are needed to better gauge the influence of urbanization and agricultural drainages.

Impacts from Increase Discharge and Surface Runoff

Impacts from increased discharge and surface runoff can potentially benefit floodplains, resulting in nutrient rich soils. However, increased discharge and surface runoff generally have adverse biological and ecological impacts. Increased discharge and runoff contributes to channel modification (both width and depth), mass wasting, reduce groundwater discharge, loss of baseflow, and provide a transportation mechanism for pathogens.

Widening has occurred on the main channel of the Minnesota River and many of its tributaries (Lenhart et al., 2012b; Schottler et al., 2013). Although channels naturally migrate laterally over time, anthropogenic and/or climatic change factors that increase runoff and direct channel modification can accelerate rates of lateral bank erosion (Lenhart et al., 2012b; Schottler et al., 2013). Increased discharge and direct channel modifications have contributed to increased rates of channel adjustment (Lenhart et al., 2011a; Lenhart et al., 2012b; Schottler et al., 2013; MPCA, 2014). Channel straightening and widespread channelization at road crossings have exacerbated channel instability, contributing to entrenchment which leads to increased rates of bank collapse followed by an average of 68% channel widenings in the UMR (Shumm et al. 1984; Charlton, 2008; Pennington and Cech, 2010; Lenhart et al., 2011a; Lenhart et al., 2012b; Schottler et al., 2013; MPCA, 2014). Excessive water increases streamflow levels which tends to promote more frequent mass wasting events, especially along bluffs and streambanks (Charlton, 2008; Lenhart et al., 2011b).

Significant changes to the hydrological cycle occur with increased discharge and surface runoff, such as the reduction of percolation, therein decreases the recharge of groundwater. If groundwater is the primary source of water for the region, groundwater depletion not only causes subsidence, but directly impacts baseflow (Raven et al., 2008). The loss of baseflow can trigger a chain reaction, which includes the increased magnitude, frequency, and duration of floods to downstream water bodies; the immediate loss of wetland and riparian vegetation within the watershed and downstream areas; changes in channel morphology; and loss of wildlife habitat and reduction in biodiversity (Charlton, 2008; Raven et al., 2008).

Increased discharge and surface runoff has the potential to carry organic compounds and inorganic chemicals when entering a waterway (Raven et al., 2008). Most of the thousands of organic compounds found in water are human-produced chemicals, which include: pesticides; solvents; industrial chemicals; and plastics (Raven et al., 2008). The effects of human-produced organic compounds on human health is generally unknown, however, the hormone contaminants are suspected to be endocrine disruptors in aquatic organisms (Raven et al., 2008). Inorganic chemicals do not easily degrade, are persistent in the environment (Raven et al., 2008). Heavy metals, such as lead and mercury, not only detrimentally affect fish and aquatic organisms, but can bioaccumulate in human tissue as well (Raven et al., 2008).

Increased discharge and surface runoff also has the potential to transport pathogens from contaminated runoff with fecal sources. Farmers who raise livestock in Concentrated Animal Feeding Operations store animal waste in slurry lagoons or tanks (Arnell, 2002; MPCA, 2014). In the event of high intensity rain, runoff from the slurry lagoons may pollute the nearby watershed with microbial pathogens, including bacteria, viruses, protozoa, and more complex organisms that cause ill-health in humans (Meybeck et al., 1989; Arnell, 2002; MPCA, 2014).

Impacts from Increased Sedimentation

Fluvial export of terrestrial nutrients occur naturally, however, the rate is exacerbated by anthropogenic activities (Waters, 1995; Raymond et al., 2012). Fluvial systems become impaired by excessive sediment, which causes numerous ecological problems such as loss and deterioration of habitat, degradation of recreational value, and negative impact to downstream surface water quality (Waters, 1995; Uri, 2000; Zimmerman et al., 2003; Thoma et al., 2005; Raven et al., 2008; Engstrom et al., 2009b; Lenhart et al., 2009; Wilcock, 2010; Hansen et al., 2010; Belmont et al., 2011; Gran et al., 2011; Lenhart et al., 2011a; Lenhart et al., 2011b; Lenhart et al., 2012b; Gran et al., 2013; Schottler et al., 2013; Gunderson et al., 2015; EPA, 2015b). Today, the MRB contributes 7.25 times more sediment than the Mississippi and St. Croix watersheds combined (Kelley and Nater, 2000a).

Channel adjustments contribute to the suspended sediment load and violations of Minnesota’s turbidity and Index of Biotic Integrity standards (Lenhart et al., 2012b).

Suspended sediments, usually particles of silt and clay borne by normal stream currents, contribute to increased turbidity, and thus affect light transmission through the water and to the stream bed (Waters, 1995; Uri, 2000; Madej, 2004; Raven et al., 2008; Houser et al., 2010; MPCA, 2012b; Gunderson et al., 2015). Because the bottom of the food web in an aquatic ecosystem consists of photosynthetic algae and plants that require sunlight for photosynthesis, turbid water lessens the ability of aquatic primary producers to photosynthesize sunlight (Uri, 2000; Arnell, 2002; Madej, 2004; Raven et. al., 2008; Pennington and Cech, 2010; Gunderson et al., 2015). Extreme turbidity impacts the primary produces by decreasing the rate of photosynthesis, which reduces the dissolved oxygen content available, which in turn decrease the number of aquatic organisms in a watershed (Waters, 1995; Uri, 2000; Madej, 2004; Raven et al., 2008; Houser et al., 2010; MPCA, 2012b; Gunderson et al., 2015).

Accumulation of fine sediment fills in lakes and reservoirs, and on streambeds, decreases the population and diversity of biotic communities by depositing coarse bed materials with fine sediment (Waters, 1995; Zimmerman et al., 2003; Madej, 2004; Pennington and Cech, 2010; Lenhart et al., 2011a; Gunderson et al., 2015). Accumulation of excess sediment not only obstructs the proliferation of submerged vegetation (Uri, 2000; Arnell, 2002; Raven et al., 2008; Pennington and Cech, 2010) but also reduces the habitat availability for fish and other aquatic organisms (Waters, 1995; Zimmerman et al., 2003; Lenhart et al., 2011a; Lenhart et al., 2011b). Aggregation of excess sediment also reduces the heterogeneity of the streambed and niche availability for fish and invertebrates, impacting colonization, feeding, and shelter (Waters, 1995; Pennington and Cech, 2010; Lenhart et al., 2011a; Gunderson et al., 2015).

The loss or reduction of fish and aquatic invertebrate populations has long been associated with turbidity and siltation of streams (Waters, 1995; Madej, 2004; Gunderson et al., 2015). The direct effect of increased sediment on fish response suggests that fish elude streams and reaches with higher suspended sediment levels, creating environments devoid of fish as though they had been killed (Birtwell et al., 1984; Scannell, 1988; Servizi and Martens, 1992; Waters, 1995; Gunderson et al., 2015). Sediment can not only attach to biological surfaces of plants and animals disrupting respiratory and reproductive functions (Servizi and Martens, 1992; Gunderson et al., 2015), but can carry toxic chemicals and nutrients that affect invertebrate hormones and behaviors (Waters, 1995; Raven et al., 2008). Aquatic invertebrates are significant to the MRB fluvial system because they are primary indicators of past and present physical, chemical, and biological conditions (MPCA, 2012b).

Nutrient concentration and flux in the Mississippi River have increased significantly over the last century due to anthropogenic impacts, changes in land use, and climate and hydrology, such as urbanization (12%), agricultural activities (70%) and atmospheric deposition (16%), which reflect trophic changes and increased algal productivity in Lake Pepin (Engstrom et al., 2009b; Houser et al., 2010; Houser and Richardson, 2010). Inflow records of nutrient changes to Lake Pepin showed largest increases after 1970, this nutrient loading of Nitrogen (N) and Phosphorus (P) can potentially lead to river eutrophication (Engstrom et al., 2009b; Houser et al., 2010). Eutrophication is the result of excess N and P entering in the water body due to adjacent land uses (MPCA, 2012b). An example of such can be seen in the UMR. The Minnesota River joins the Mississippi River, and excess nutrients from near field sources of both rivers promote algae growth, when the algae die, they sink to the bottom and are decomposed by the bacteria, which deplete the water of dissolved oxygen, leaving little oxygen for other aquatic life, this oxygen free condition in the Gulf of Mexico is known as hypoxia (Waters, 1995; Raven et al., 2008; Lenhart et al., 2011b; MPCA, 2012b; Raymond et al., 2012). The majority of N and P transported to the Gulf originates from agricultural basins of Southern Minnesota; it has been estimated that the UMR contributes about 32% of the NO_3^- load and 35% of the total P load to the Gulf (Houser and Richardson, 2010). The increase in nutrient flux from the Mississippi River has greatly affected the Gulf by increasing primary production, changing phytoplankton community composition, and increasing the temporal and spatial extent of hypoxia in the Gulf (Houser and Richardson, 2010).

Lake Pepin

Lake Pepin, a natural riverine situated on the Mississippi River, is approximately 95 km southeast of St. Paul, Minnesota, and is a significant recreational and commercial entity for the surrounding region (Engstrom et al., 2009b; Gran et al., 2009; Schottler et al., 2010; Kessler et al., 2011). The morphology of Lake Pepin is reflected in part by the presence of glacial outwash terraces and the alluvial fans of tributary streams

(Blumentritt et al., 2009). With a surface area of roughly 100 km^2, Lake Pepin was formed by the sediment deposited by the Chippewa River, which dammed the Mississippi River valley (Blumentritt et al., 2009; Engstrom et al., 2009b; Gran et al., 2009; Mulla and Sekely, 2009; Schottler et al., 2010; Faulkner et al., in Press). Lake Pepin, which traps nutrients and sediments entering from the Mississippi River, is a nearly unique impoundment because of its ability to accumulate sediments conformably, allowing numerous studies to use paleolimnological methods to examine long-term environmental change in large fluvial systems, including the pre-settlement period so lacking in records from man-made reservoirs (Kelley and Nater, 2000a; Blumentritt et al., 2009; Engstrom, 2009a; Engstrom et al., 2009b; Schottler et al., 2010). Over the past 150 years, the rate of that sediment supply has increase ten-fold, from 79,000 t/yr. before c. 1830 to 876,000 t/yr. during the 1990s (Engstrom et al., 2009b; Gran et al., 2009; Mulla and Sekely, 2009; Schottler et al., 2010; Belmont et. al., 2011).

An analysis of the chemical constituents of the sediment delivered to Lake Pepin indicates that between 80-90% of the sediment entering Lake Pepin comes from glacial deposits located predominantly in the MRB (Kelley and Nater, 2000b; Gran et al., 2009; MPCA, 2009; Mulla and Sekely, 2009; Schottler et al., 2010; Wilcock, 2010; Belmont et al., 2011; Gran et al., 2011; Lenhart et al., 2011a). Schottler et al. used radioisotope fingerprinting to quantify the different erosion sources, and determined that the sources of sediment derive from near-channel sources in the BERB and LSRB, primarily ravines and bluffs (2010). Only a fraction of the total amount of sediment erosion occurring in the MRB and its subbasins makes its way out to the river mouth and Lake Pepin (Hansen et al., 2010). This is partly due to a flat topography, a poorly defined drainage network over much of the southern and western MRB and the great distance required for sediment to travel to reach the river mouth (Hansen et al., 2010). Recent studies have focused specifically on the BERB and LSRB which together contribute as much as half of the sediment to Lake Pepin and the Minnesota River, even though they only account for one-fifth of the Minnesota River's drainage area (Magner and Steffen, 2000; MPCA, 2009; Lenhart et al., 2010; Wilcock, 2010; Lenhart et al., 2011a; MNBWSR, 2011; MPCA, 2013).

Drawing conclusions from current sediment accumulation rates, the remaining volume of Lake Pepin (553 x 10^6 m^3 in 1990) is anticipated to be filled completely in roughly 340 years (Engstrom et al., 2009b). With the increased accumulation rates of approximately 3-4 cm yr^{-1}, the shallow upper third of Lake Pepin will lack recreational or commercial value within a century (Kelley and Nater, 2000a; Engstrom et al., 2009b). Without the increased accumulation of sediment loading, today, Lake Pepin would be on average 1 m deeper, and could continue to provide recreational and commercial value for another 4,000 years (Kelley and Nater, 2000a; Engstrom et al., 2009b). Therefore, restoration of the MRB and its subbasins would provide a multitude of economic and social benefits to the immediate adjacent region, as well as the downstream entities.

Within Blue Earth County, there are hundreds of eroding ravines and bluffs along its 592 km of rivers and streams, and 300 km of unnamed and intermittent streams (Blue Earth County, 2013; MNBWSR, 2011). Erosion from these areas are a water quality concern, as well as a potential threat to dwellings, roadways, and infrastructure (Shields et al., 1995; Soulsby et al., 2001; Liu et al., 2009; Day et al. 2013a). Studies have determined that sources of sediment primarily derive from near channel sources in the BERB and LSRB, specifically from ravines and bluffs. However, the method of determining the geographic location of specific near channel sources is insufficient, (MPCA, 2009; Belmont et al., 2011). Wilcock (2010) stated that actions to reduce sediment loading require identification of not only the subbasin from which the largest amounts of sediment derive, but the specific location within the subbasin. Therefore, in order to direct restoration efforts, a protocol of identifying critical ravines and bluffs is necessary for effective water resource management (MPCA, 2009; Belmont et al., 2011).

Objective 1: Using multi-temporal LiDar datasets to identify a complete inventory of ravines and bluffs within the BERB and LSRB.

Study Area

The study area for this research is the BERB and LSRB within the Blue Earth County boundary (Figure 1) and were selected because of high sediment contributions to Lake Pepin. Also, there are two LiDar data scans (2005 and 2012) from Blue Earth County that allowed for spatial interpolation of the volume of erosion between those years to identify and locate sites of greatest erosion.

Both watersheds have tall banks with sloughing that can be as tall as 50 m in a broad valley (Bauer et al., 2002; Kessler et al., 2011). Exposed tree roots, fallen material accumulation at the toe, lack of vegetation, and dead trees in the river indicate active bank sloughing (Kessler et al., 2011). Waterways in the BERB and LSRB are lined with shrubs and trees, making access difficult, limiting access to primarily watercrafts, such as canoes or kayaks (Kessler et al., 2011). Many of the tall banks within the BERB and LSRB are sheer cliffs with gradients as high as 80 degrees, therefore, surveying these banks with conventional methods and equipment can potentially be dangerous, laborious, time consuming, and infeasible (Bauer et al., 2002; Kessler et al., 2011).

The use of Digital Elevation Models (DEMs), created from LiDar data, in GIS software, provide fast, non-invasive, and cost effective methods of summarizing land surface information, quantifying erosion, and identifying critical erosive sites safely compared to conventional ways of collecting topographic information (Chowdary et al., 2008; Kessler et al., 2011; Ashraf et al., 2012; Yuan et al., 2012).

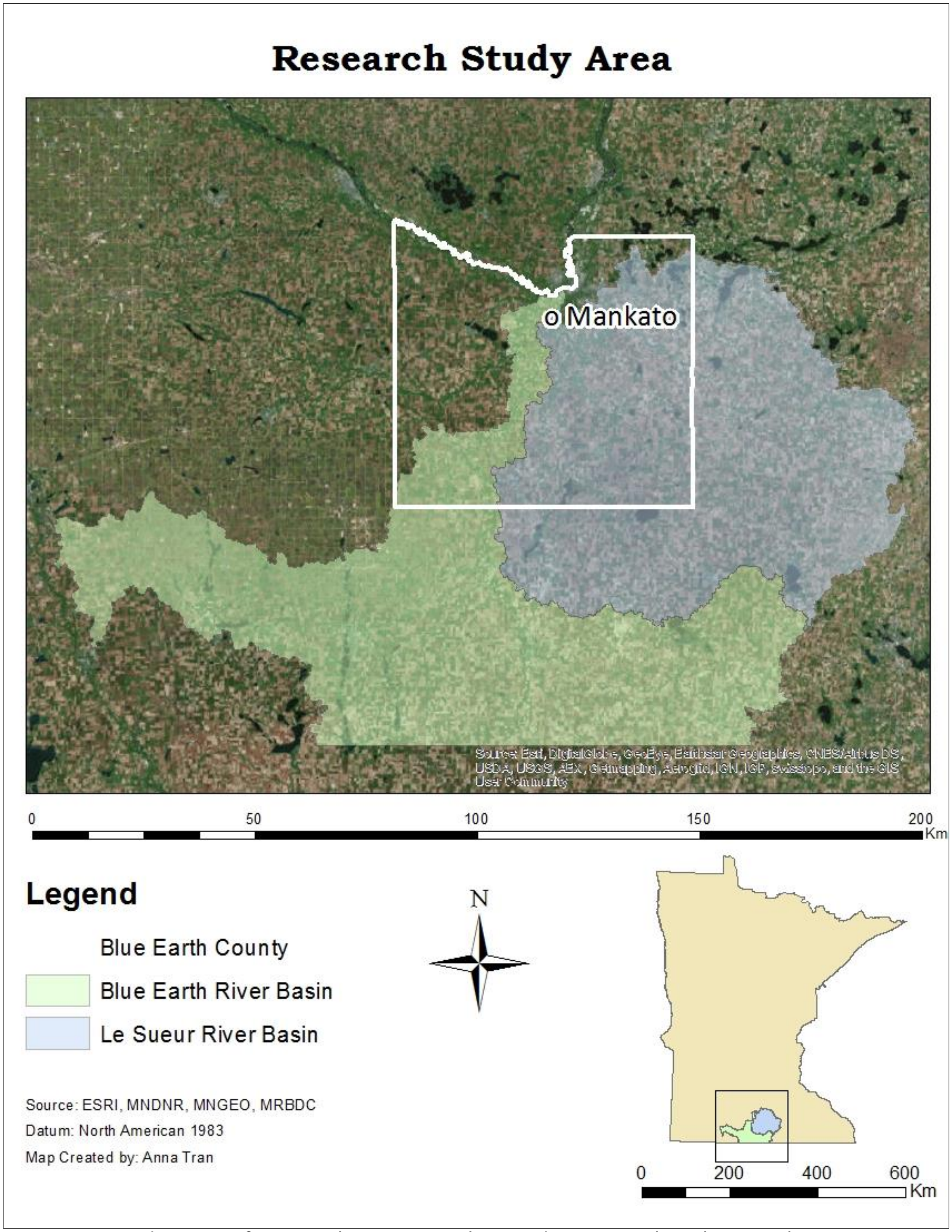

Figure 1. Study area of research project. The study area is the Blue Earth River Basin and Le Sueur River Basin within the Blue Earth County boundary line (white).

Geographic Information Systems (GIS) and Remote Sensing (RS)

GIS provides suitable alternatives for efficient management of large and complex databases (Chowdary et al., 2008). RS is the acquisition and interpretation of information about the environment and the surface of the earth from a distance, primarily by sensing radiation that is naturally emitted or reflected by the Earth's surface or from the atmosphere, or by sensing signals transmitted from a device reflected back to it (ESRI, 2015). DEMs are computerized representation of land surface arrangement which can be created through RS data (Ashraf et al., 2012). Data acquired through RS can be analyzed in GIS software. Thus, the blending of RS and GIS technologies is a widely accepted tool for water resources development and management (Chowdary et al., 2008; Pennington and Cech, 2010).

Airborne LiDar is an active RS technique that includes the use of the Global Positioning System (GPS), Inertial Navigation System and a laser distance scanner (Chen et al., 2006; Bailly et al., 2012). LiDar operates in the infrared, visible, or ultraviolet wavelengths of the electromagnetic spectrum (Bailly et al., 2012). A LiDar data scan is collected by sending thousands of laser pulses to the ground each second from a LiDar instrument, typically attached to an aircraft, and recording the travel time for their returns (Pennington and Cech, 2010; Kessler et al., 2011). After data points are collected, LiDar data can be processed to construct high-precision DEM data, facilitate detection of minor changes in elevation, and reveal subtle geomorphic features within an entire area (Chen et al., 2006). LiDar can be processed to reveal the topography beneath vegetation (Schulz, 2007). Airborne LiDar data of a river valley taken at two different times provide an estimate of the change in the volume of the valley as a result of bank erosion, sloughing, and accretion (Thoma et al., 2005). Schulz (2007) found that LiDar yielded four times more critical areas than aerial photos.

<u>LiDar Data</u>

2005 LiDar data

The first LiDar data set (Figure 2; Figure 4 – with Hillshade) originated from Optimal Geomatic Inc. using an Optech 3100 ALTM 70 kHz laser system and Realm Terrascan and Geocue Survey processing software mounted on a fixed-wing aircraft (MNGEO, 2012; Schaffrath et al., 2015). The first data set was collected under contract by the county, flown at 1836 m above ground, and over two periods, April 13-14, 2005, and April 23-24, 2005, thus data are not entirely consistent with the other LiDar data available in Minnesota and had to be adjusted in post processing (MNGEO, 2012).

Raw LiDar data were processed by the vendor using proprietary software to produce bare earth points, hydrologic breaklines, and 0.6 m contours (Kessler et al., 2011). Vertical accuracy of the data was estimated by the vendor by calculating the Root Mean Square Error (RMSE) of elevations for 350 checkpoints collected within four subareas in different land cover types (MNGEO, 2012; Schaffrath et al., 2015). The data had a vertical RMSE of 0.15 m and a horizontal RMSE of 1 m (Gran et al., 2013). The accuracy was checked by the Minnesota Department of Transportation (MNDOT) using ground truth data with a total of 351 points collected with real-time kinetic GPS over a variety of land covers (Kessler et al., 2011). Data were distributed in North American

Datum 1983 in Universal Transverse Mercator, zone 15N, and coordinates with orthometric heights were converted using the GEOID03 model (Schaffrath et al., 2015).

2012 LiDar data

The second LiDar data set (Figure 3; Figure 5 – with Hillshade) originated from AeroMetric Inc. using a Leica ALS 70 LiDar system and processing software mounted on a fixed-wing aircraft (MNGEO, 2014; Schaffrath et al., 2015). The data for this dataset was flown at 2400 m above ground with a swatch width of 40 degrees and a 30% sidelap, and collected in the spring of 2012, specifically on April 6, 2012 (MNGEO, 2012; Schaffrath et al., 2015). This data set was collected under contract by the Minnesota Department of Natural Resources (MNDNR) in several formats: 1) one-meter DEM; 2) edge-of-water breaklines; and 3) classified LASer (LAS) formatted point cloud data; MNDNR staff created two additional products: two-foot contours and building outlines (MNGEO, 2012). Vendors collected 145 checkpoints that were spatially distributed throughout the county, and reported vertical accuracy (Schaffrath et al., 2015). Vertical accuracy was to achieve a RMSE-Z of 12.5 cm (95% confidence level of less than 24.5 cm) or better in the "Open Terrain" land cover category for all areas in accordance with National Digital Elevation Program and American Society for Photogrammetry and Remote Sensing methodologies (MNGEO, 2012). Data were distributed in the North

American Datum 1983 in Universal Transverse Mercator, zone 15N, and coordinates with orthometric heights converted with GEOID09 (Schaffrath et al., 2015).

Data Discrepancies

As the capacity to collect high resolution terrestrial scans on larger spatial scales increase, the challenges of quantifying and reporting error also increases (Schaffrath et al., 2015). Generic error values reported by vendors may underestimate actual uncertainty and do not capture the spatially variable nature of uncertainty that is needed for meaningful geomorphic change detection (Schaffrath et al., 2015). Thus, data discrepancies between datasets exist. Data discrepancies of the 2005 and 2012 LiDar datasets include variability in vertical bias attributed to different geoid models and localized offset strips in the DEM of difference from poor coregistration of the flightlines (Schaffrath et al., 2015). LiDar data variability can be attributed to uncalibrated flightlines, timing discrepancies, vegetation density, and water level (in 2005, water level was ~1 higher than in 2012) (Schaffrath et al., 2015).

As a method-based study, the subtraction of two raw, unrectified DEMs provides a coarse estimate of erosion and elevation change. Raw DEM calculations yield a minimum level of detection analysis, but the overall erosion and deposition results are grossly overestimated (Schaffrath et al., 2015). Therefore, due to data discrepancies, the 2005 and 2012 LiDar dataset cannot be simply subtracted for quantifiable data. Schaffrath et al. (2015) details methods to rectify the discrepancies in the data.

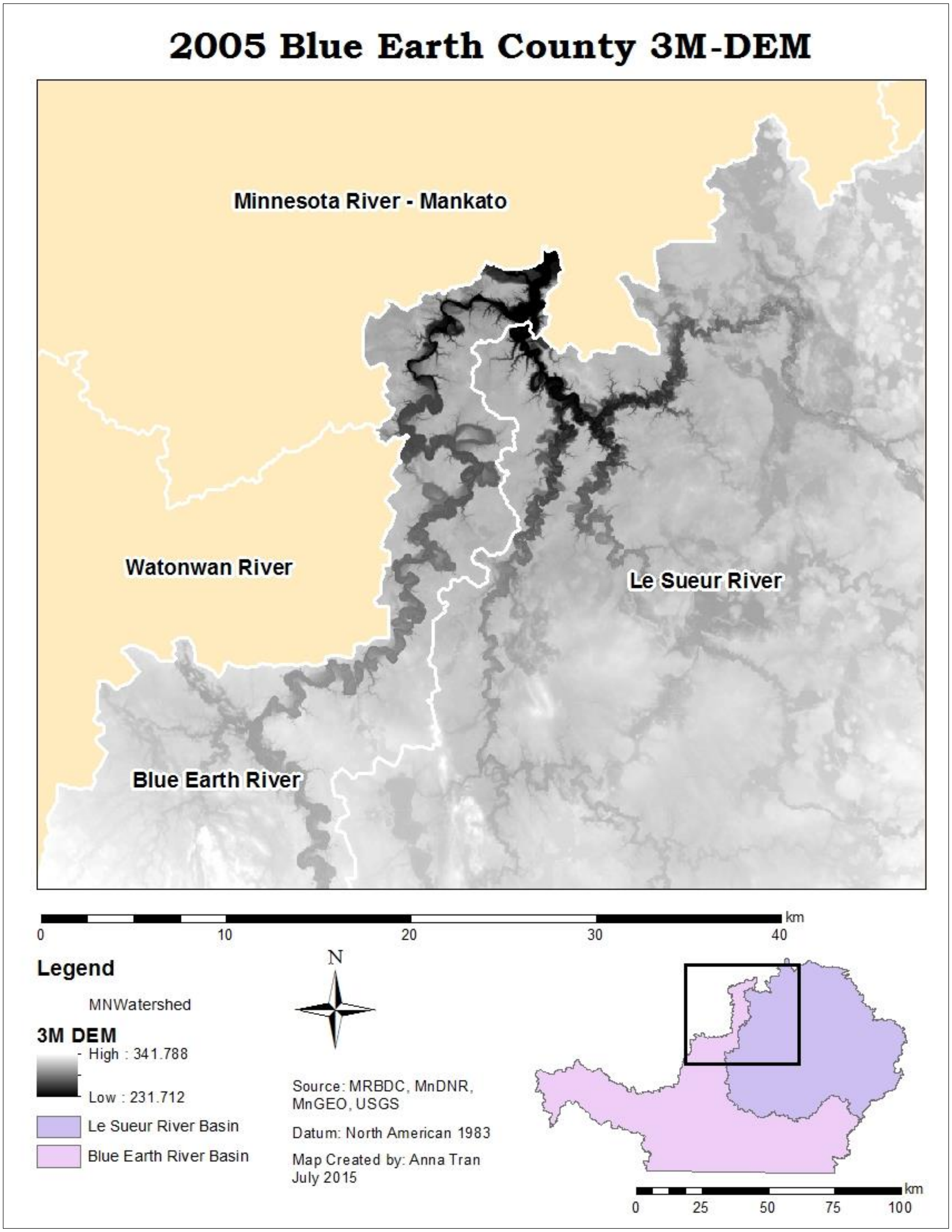

Figure 2. 2005 Blue Earth County 3M-DEM data derived from LiDar points.

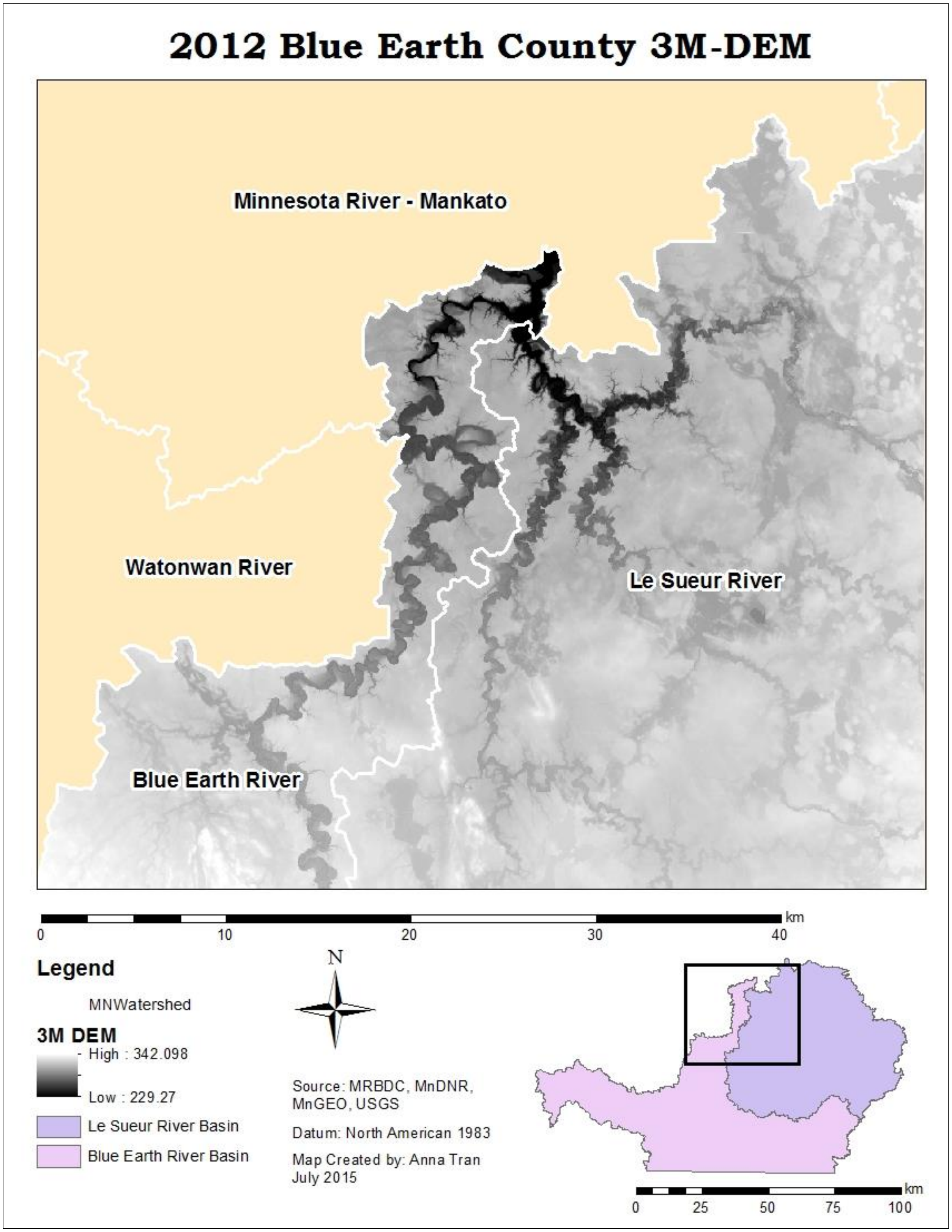

Figure 3. 2012 Blue Earth County 3M-DEM data derived from LiDar points.

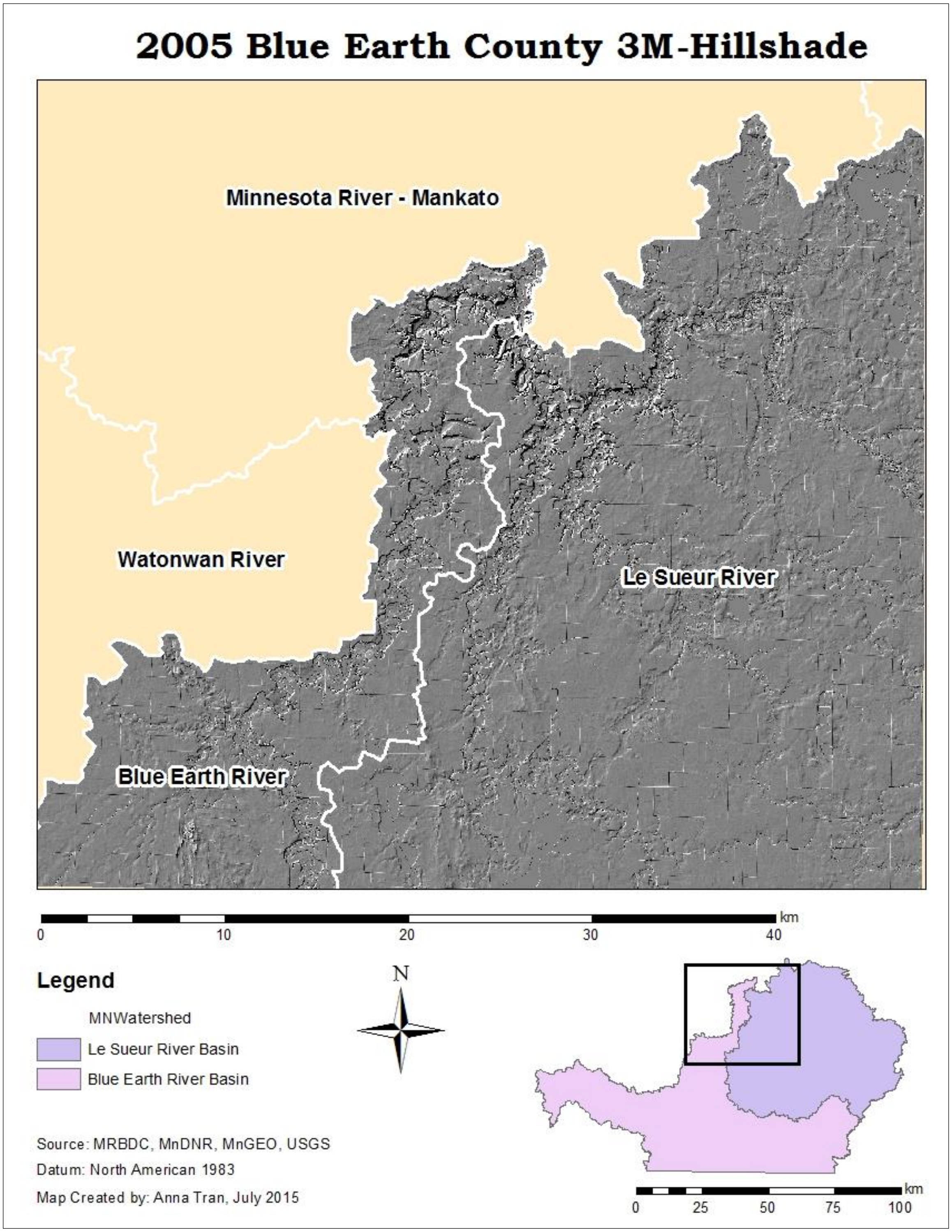

Figure 4. Blue Earth County 2005 3m Hillshade for the Blue Earth River Basin and Le Sueur River Basin, processed from the 2005 3m DEM (Figure 2). This allows the users to see the topography of the study area in detail.

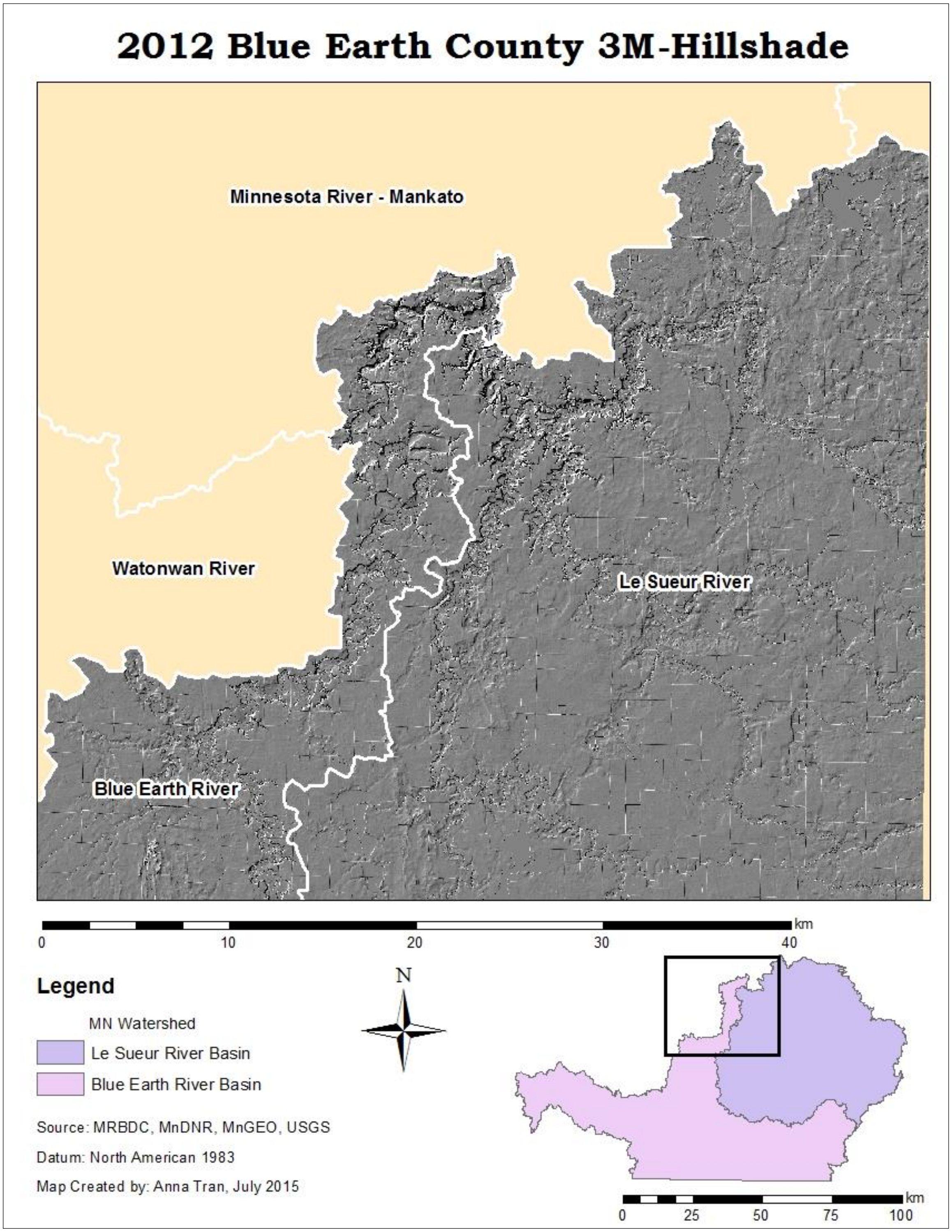

Figure 5. Blue Earth County 2012 3m Hillshade for the Blue Earth River Basin and Le Sueur River Basin, processed from the 2012 3m DEM (Figure 3). This allows the users to see the topography of the study area in detail.

Criteria Influencing Sediment Transport

Criteria influencing sediment erosion and delivery include soil characteristics such as: texture, structure, and cohesion; slope, vegetation cover, and climate factors (Czapar et al., 2006; Charlton, 2008). High levels of sediment pollution and erosion can be expected in areas where catchment rock is highly erodible, where relief is steep, where vegetation is low, and where rainfall is intense (Arnell, 2002).

Both the texture and structure of the soil influence its erodibility, or susceptibility to erosion (Leopold et al., 1964; Pimentel et al., 1995; Charlton, 2008). Texture refers to the size or combination of sizes of the individual particles, and structure refers to the degree to which the soil particles are clumped together, forming larger clumps and pore spaces (Raven et al., 2008). Coarse textured sediment and sediment from sheet and rill erosion are less likely to reach a stream than fine-grained sediment or sediment from channel erosion (Czapar et al., 2006; Pimentel, 2006). Soils with medium to fine texture, low organic matter content, and weak structural development have low infiltration rates and experience increased water runoff (Foster et al., 1985; Allan, 1995; Pimentel et al., 1995; Pimentel, 2006).

Generally, the greater mass of larger particles requires higher current velocities to initiate movement, thus, particles with smaller mass (e.g. fine silts) are more susceptible to erosion (Allan, 1995; Arnell, 2002). Structure influences the ability of the soil to absorb water and its physical resistance to erosion (Raven et al., 2008). Cohesion is the final soil characteristic property to consider, cohesion is the binding force between soil particles and influences the structure (Arnell, 2002; Raven et al., 2008).

When the soil is moist, the soil particles bind together (e.g. clay soils are cohesive, while sands are not) (Arnell, 2002; Raven et al., 2008). In the BERB and LSRB, soils are highly variable,

Erosion increases dramatically on long or steep slopes (~15 degrees or 30% or more) where runoff can reach high velocities (Pimentel et al., 1995; Hilliard and Reedyk, 2014; Ritter and Eng, 2012). A study of relationship between slope gradient and other morphometric slope and gully parameters in laterite terrain suggests that slope gradient alone explains about 63% of the spatial variations in the intensity of hillslope erosion (Ebisemiju, 1988). Ebisemiju (1988) observed two threshold limits which he found significant, the first is a critical combination of slope length 225 m and slope gradient of 3-5 degrees (10%); the second threshold limit is hill slope gradient equal to the gradient of 20 degrees (~40 %).

Soil erosion by water increases as the slope length increases due to the greater accumulation of runoff (Arnell, 2002; Czapar et al., 2006; Ritter and Eng, 2012). The greatest erosion potential is located at the base of the slope, where the runoff concentrates, and the runoff velocity is the greatest (Czapar et al., 2006). Yet steep slopes are now routinely being converted from forest for agricultural use because of the increasing needs of human population and land degradation (Lal and Stewart, 1990). Slope steepness, surface roughness, and the amount and intensity of rainfall control the speed at which runoff flows down a slope (Pimentel et al., 1995; Czapar et al., 2006). The steeper the slope, the faster the water will flow, the faster the water flows, the more likely it will cause erosion and increase sedimentation (Pimentel et al., 1995). In the Philippines, where over 58% of the land has slopes greater than 11% (~6 degrees), and Jamaica, where 52% of the land has slopes greater than 20% (~11 degrees), exhibit soil loss as high as 400 tons ha^{-1} yr^{-1} (Lal and Stewart, 1990).

Vegetation can be a huge factor influencing soil erosion. A good canopy of vegetation shields the soil from the impact of precipitation, this is called interception (Arnell, 2002; Charlton, 2008). Once precipitation is intercepted on the canopy, it drips off of the leaves through the canopy, this is known as throughfall, and a portion of the precipitation runs down the trunk as stemflow (Arnell, 2002). This greatly reduces the impact on surface soils; a vegetative cover not only provides organic matter, but slows runoff and filters sediment (Charlton, 2008).

Organic material, in the form of dead and decaying biomass plays several important roles: it holds the topsoil together, increases permeability and provides a supply of nutrients (Charlton, 2008); the removal of natural vegetation greatly reduces soil protection, and rates of soil erosion may accelerate (Pimentel et al., 1995; Charlton, 2008; Raven et al., 2008). In Oklahoma, areas without rye grass or wheat cover lost 2.5 - 4.8 times as much water as land with cover (Sharpley and Smith, 1991).

The climate factors that influence erosion are rainfall amount, frequency, and intensity (Arnell, 2002). During periods of high frequency precipitation, a greater percentage of rainfall will become runoff, or overland flow (Arnell, 2002). This is attributed to high soil moisture content or saturated conditions where the soil can no longer hold water. Temperature is another climatic factor that influences erosion. In areas with heavy snowfall, the frozen soil is resistant to erosion, however, the rapid thawing of the soil surface from warm rains can lead to serious erosion (Arnell, 2002). Temperature also influences the type of precipitation; falling snow does not erode, substantial snow melts in the spring, however, leads to higher potential runoff damage (Arnell, 2002).

These factors that contribute to the erosion potential were used in conjunction with existing data to derived parameters to prioritize these ravines and bluffs. Based on available data, the soil material, soil texture, and slope data were derived/applied as criteria to prioritize sites. The soil material of the ravines and bluffs both in the BERB and LSRB varied from gray lacustrine to gray till, with many sites containing both materials. Lacustrine deposits are well sorted, devoid of coarse particles such as sand or gravel (UBC, 2015). The soil texture consisted of fine-loamy, fine-silty, fine, very-fine, to coarse-loamy, all of which exhibit erosive behavior (Ritter and Eng, 2012). Although all soils are potentially susceptible to water erosion, silts, silt loams, and loams are most at risk (Pimentel, 2006; Hilliard and Reedyk, 2014). They are small in size compared to sandy soils, and do not bind together like clay, and are subject to the most erosion (NCSU, 2012). Typically, these soils have low water infiltration rates, and therefore are subject to high rates of water erosion (Pimentel, 2006).

The BERB and LSRB are relatively flat areas, with 54% of the land having <2% slope, and 93% of the land exhibiting <6% slope (Kessler et al., 2011). In many areas, the slope of ravine and bluff sites can reach as high as 80 degrees (Bauer et al., 2002; Kessler et al., 2011). The MRB has a trend with less vegetative cover at the headwater areas, and more vegetative cover moving toward the river (MNDNR, 2015c). The southwest and western portion of Minnesota have less than 40% perennial vegetative cover remaining, this is in part due to the conversion of native vegetation to agricultural land uses (MNDNR, 2015c). The MNDNR ranks both the BERB and LSRB with a low Perennial Cover Health Score of zero (2015c).

Increases in total rainfall of up to 20% have occurred in Minnesota over the past 90 years (Seeley, 2008; MPCA, 2012b). Precipitation in the BERB and LSRB averages from 69 to 84 cm annually, increasing from northwest to southeast (MPCA, 2012b). In the BERB and LSRB, spring melt typically occurs between the end of March and early April (MPCA, 2012b). Combined with soils lacking cover crop, snowmelt in the BERB and LSRB may increase overland runoff across frozen soils, raising the levels of streams (MPCA, 2012b).

Methodology

In order to acquire a complete inventory of ravines and bluffs within the BERB and LSRB, the necessary GIS data were gathered from various Minnesota State Agencies and public data centers. Data include a compilation of county LiDar and elevation, watershed and stream network, county infrastructure (private and public buildings and roads), county and watershed soil, county and watershed land use data in the BERB and its subbasins. In order to ensure homologous maps, the files were displayed on the Projected Coordinate System (PCS): North American Datum (NAD) 1983 Universal

Transverse Mercator (UTM) coordinate system for zone 15N. The files were all transformed to the Transverse Mercator map projection and clipped to the BERB and LSRB in Blue Earth County.

The 2005 and 2012 Blue Earth County LiDar data were acquired and superimposed. From the ArcToolbox, a spatial analysis - minus was conducted on the 2005 and 2012 3m DEM data to determine the coarse net volume change in soil erosion from 2005 to 2012 (Figure 6), and to target areas where major erosion has been occurring during that time frame. A slope degree analysis was conducted on the output of the spatial analysis to determine the slope of the volume change and soil loss from 2005 and 2012 (Figure 7). A slope degree analysis was also conducted on the 2012 3m DEM to determine the most current slope gradient information for ravines and bluffs within the BERB and LSRB (Figure 7). Additionally, an aspect was conducted on the 2012 3m DEM to display the direction of the slope face, both in ravines and bluffs (Figure 9). Aspect can determine the southerly slopes to identify locations where the snow is likely to melt first, or identify locations likely to be hit by runoff first.

Based on the superimposed output from the spatial and slope degree analyses, the ravines and bluffs within the BERB and LSRB were located and manually digitized into a new shapefile. The digitized files yielded a preliminary comprehensive inventory of critically erosive ravines and bluffs based on coarse net sediment loss, slope grade, soil material, soil texture, connectivity to river, distance to river, surrounding adjacent land use, proximity and threat to roads, proximity and threat to public and private buildings, accessibility from roads, visibility from stream, and visibility from roads. The total amount of ravines in the BERB were 59 (Figure 10); the total amount of bluffs in the BERB were 96 (Figure 11); the total amount of ravines in the LSRB were 62 (Figure 12); and the total amount of bluffs in the LSRB were 376 (Figure 13).

Data management of these files were crucial in understanding the data to determine which sites contributed the most amount of soil to the rivers. There were multiple shape files that were needed within Blue Earth County, such as: the major and minor watersheds; Blue Earth County roads; infrastructure (private and public buildings and roads) within the county; county and watershed soil data; and county and watershed land use data. The varying shape files were overlaid to determine parameters and well as fill in data gaps on the attributes table. Each site contains site-specific scientific data on: watershed location, GPS; area of the site, soil properties and characteristics; distance and proximity to the main river channel, connectivity of the channels to the main river; and surrounding and adjacent land use.

With a total of 121 ravines and 472 bluffs, it would be impractical and unfeasible to restore every single site due to limited economic resources, thus further narrowing down the sites based upon the proposed socio-economic criteria were necessary to determine high priority sites. The sites that meet the socio-economic criteria were listed in a separate shape file within the provided data.

Socio-economic criteria set by the Lake Pepin Legacy Alliance were visibility from stream, visibility from the road, threat to roads and buildings, proximity to roads and site accessibility, as well as river connectivity. These criteria were also used in the comprehensive ravine mapping project completed on the Illinois shore of Lake Michigan (Shabica et al., 2010), however, for this study, these indicator criteria were applied to bluffs as well. Thus, buffers were created using the source shape files to determine which sites fall within visible range of the stream, road, and buildings. Based upon these criteria, the 121 ravines and 472 bluffs were narrowed down to 32 ravines and 39 bluffs. The BERB contained 14 ravines (Figure 14) and 10 bluffs (Figure 15), and the LSRB contained 18 ravines (Figure 16) and 29 bluffs (Figure 17), all of which met the criteria for erosive sites as well as the socio-economic criteria proposed by the Lake Pepin Legacy Alliance. The respective associated data tables were: narrowed ravines in the BERB (Table 1); narrowed bluffs in the BERB (Table 2); the narrowed ravines in the LSRB (Table 3); and lastly, the narrowed bluffs in the LSRB (Table 4). Maps were created to reflect the data for each watershed.

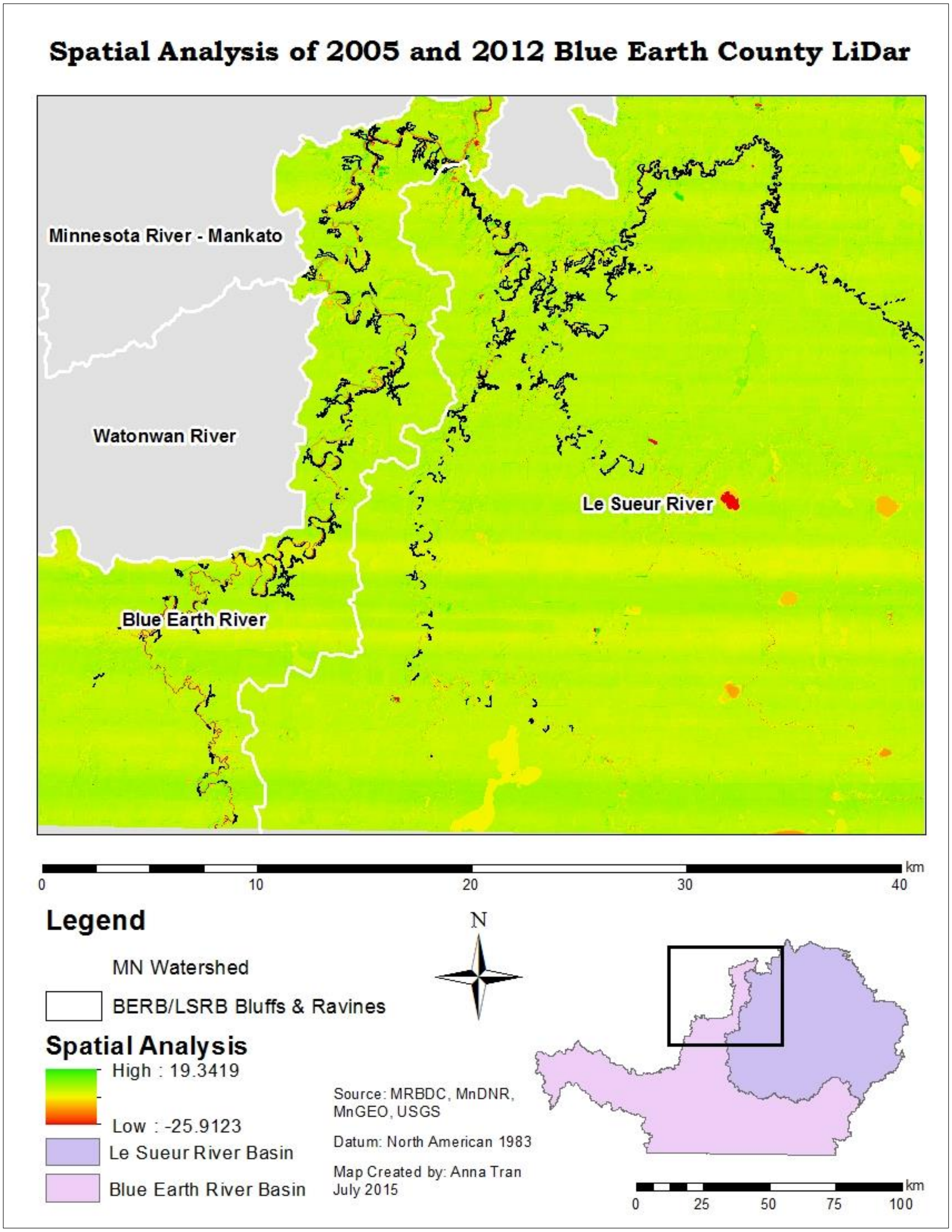

Figure 6. GIS Spatial Analysis - minus of the 2005 and 2012 Blue Earth County LiDar data. This overlay analysis computed the 3m DEM from 2005 and 2012 to determine a coarse estimate of net soil loss in elevation (cm) for the seven year period for the BERB and LSRB. Areas in red indicates the areas with the most decrease in elevation, which correlates with the area with the most erosion.

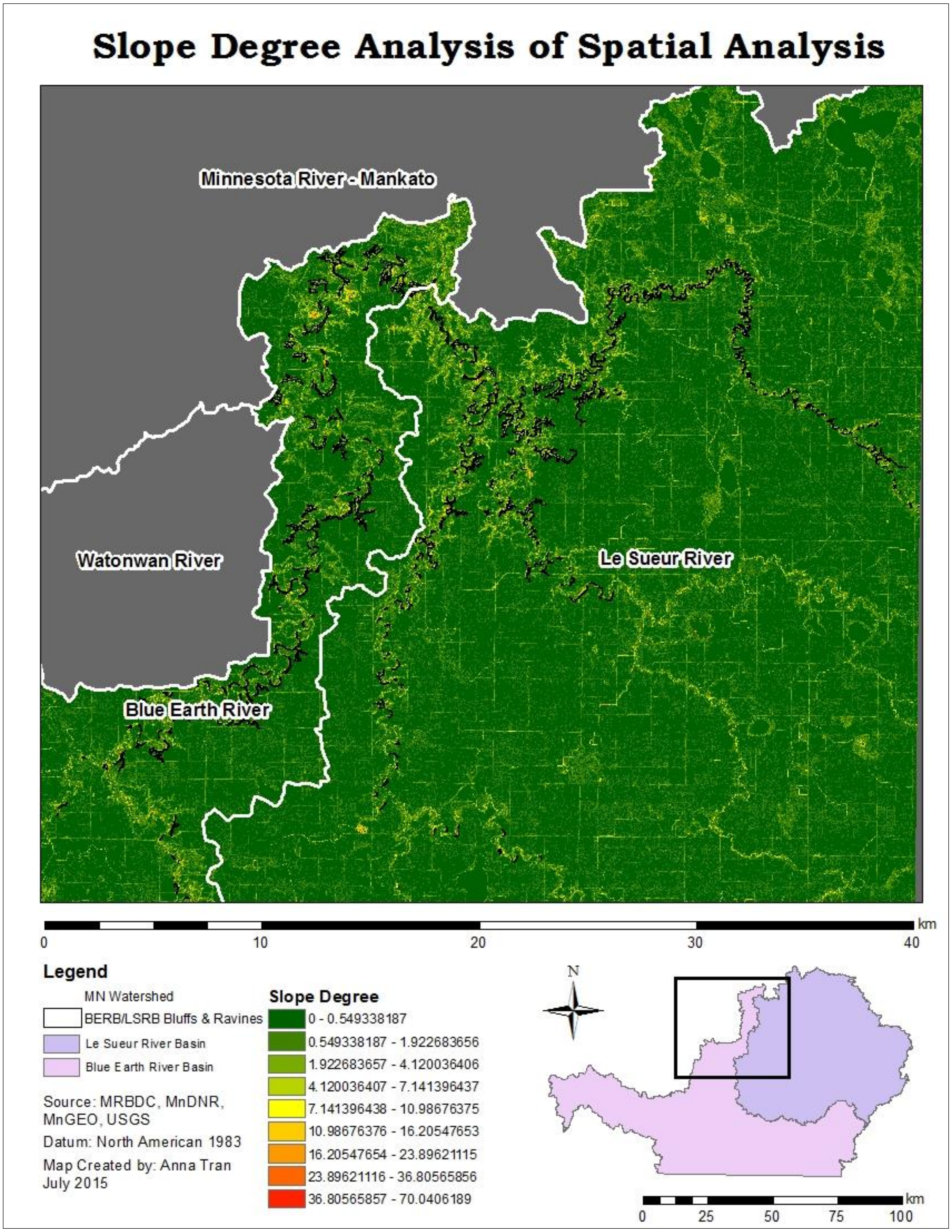

Figure 7. GIS Slope degree analysis of the spatial analysis minus of the 2005 and 2012 Blue Earth County LiDar data. The output shows the change in slope grade from 2005 to 2012.

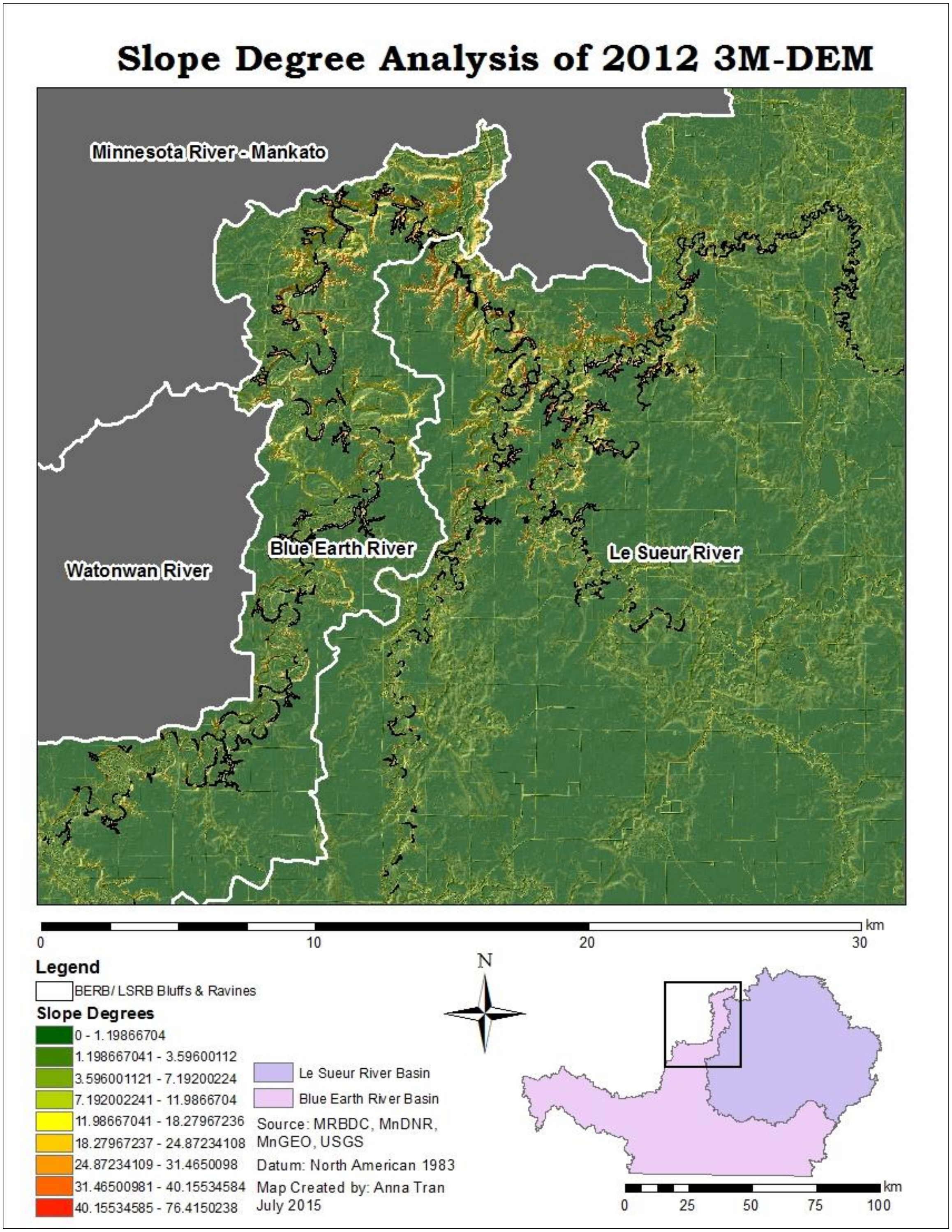

Figure 8. GIS Hillshade and Slope degree analysis of the 2012 Blue Earth County 3m DEM data. This map displays the hillshade of the 2012 DEM overlaid with the slope analysis, showing the current slope degree from the latest LiDar scans. The areas of orange and red are areas with the steepest gradients (>20°) and are prone to mass movement, severe rain splash, and sheet erosion.

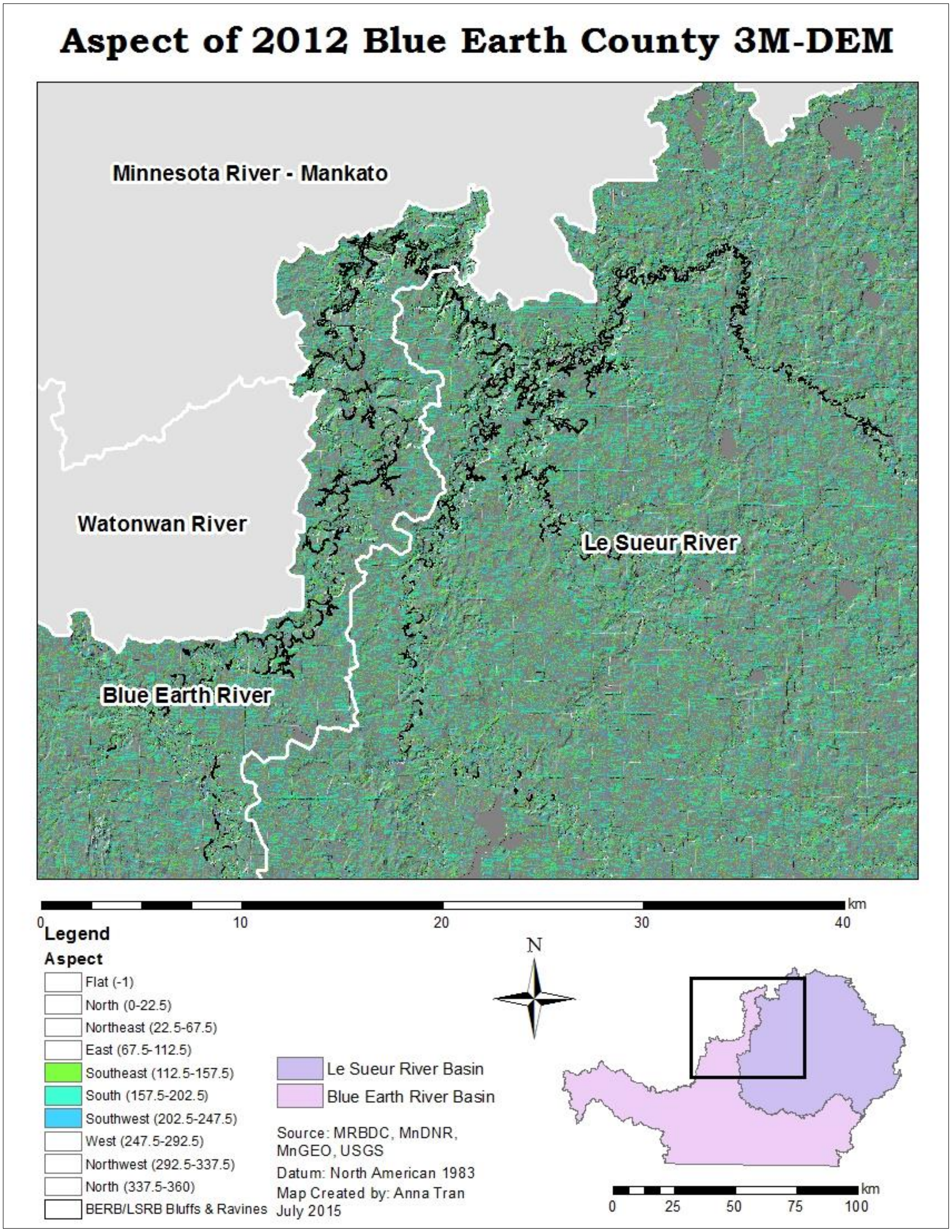

Figure 9. GIS Spatial Analysis -Aspect of the 2012 Blue Earth County 3m DEM. Aspect is the slope direction, which identifies the downslope direction of the maximum rate of change in value from each cell to its neighbor. Aspect determines the southerly slopes to identify locations where the snow is likely to melt first, or identify locations likely to be hit by runoff first.

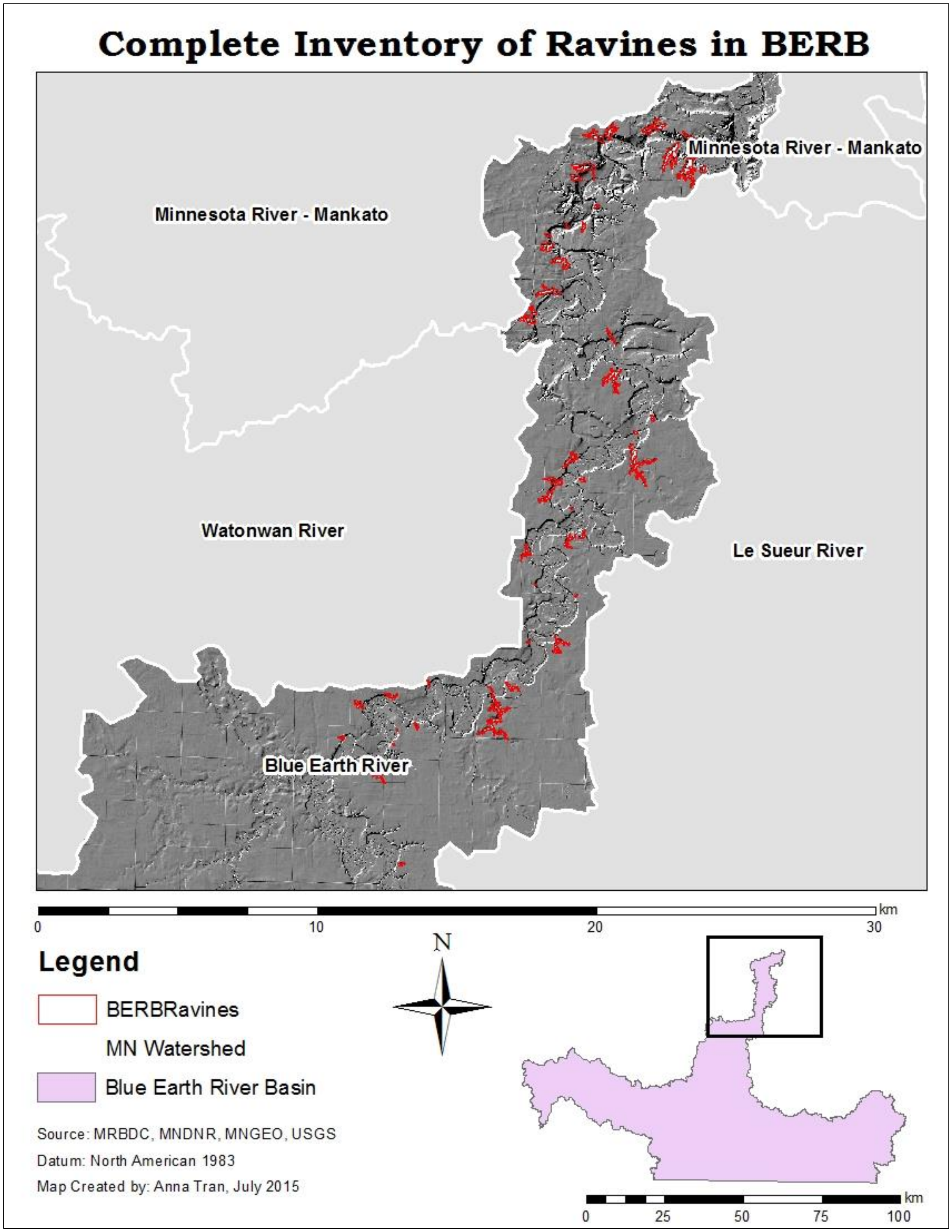

Figure 10. Derived from the spatial analysis minus and slope degree analysis, 59 ravines in the BERB were identified as areas with the largest amount of erosion from 2005 to 2012.

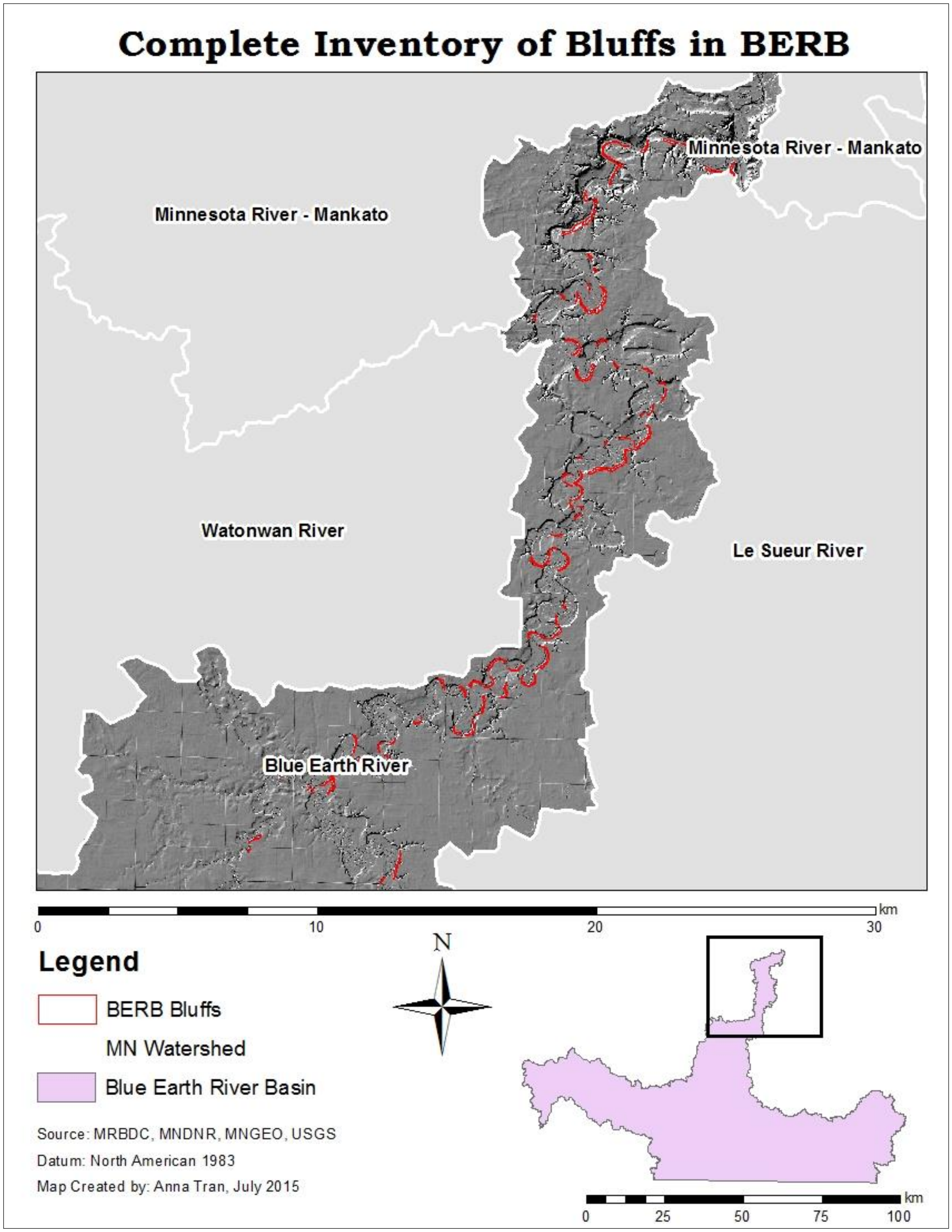

Figure 11. Derived from the spatial analysis minus and slope degree analysis, 96 bluffs in the BERB were identified as areas with the largest amount of erosion from 2005 to 2012.

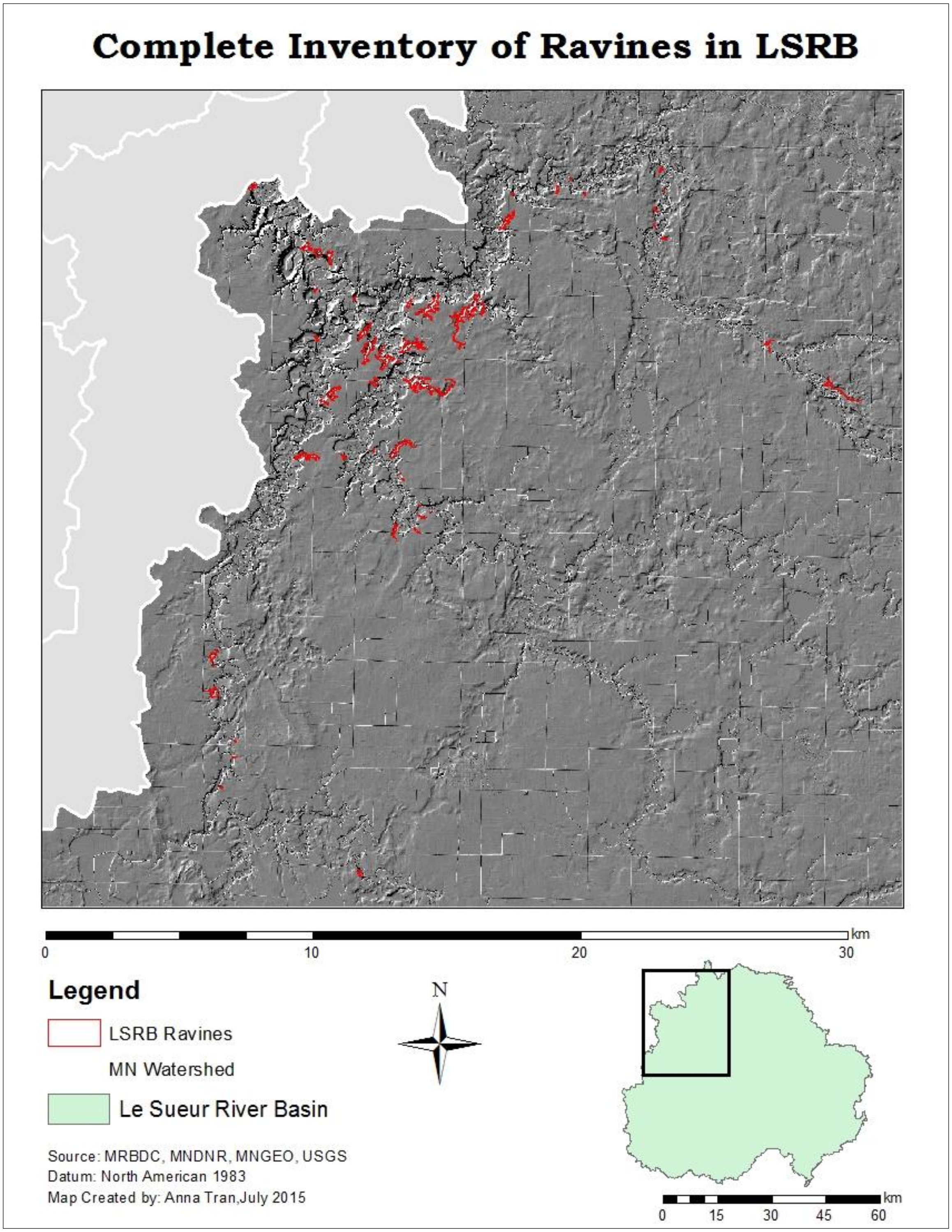

Figure 12. Derived from the spatial analysis minus and slope degree analysis, 62 ravines in the LSRB were identified as areas with the largest amount of erosion from 2005 to 2012.

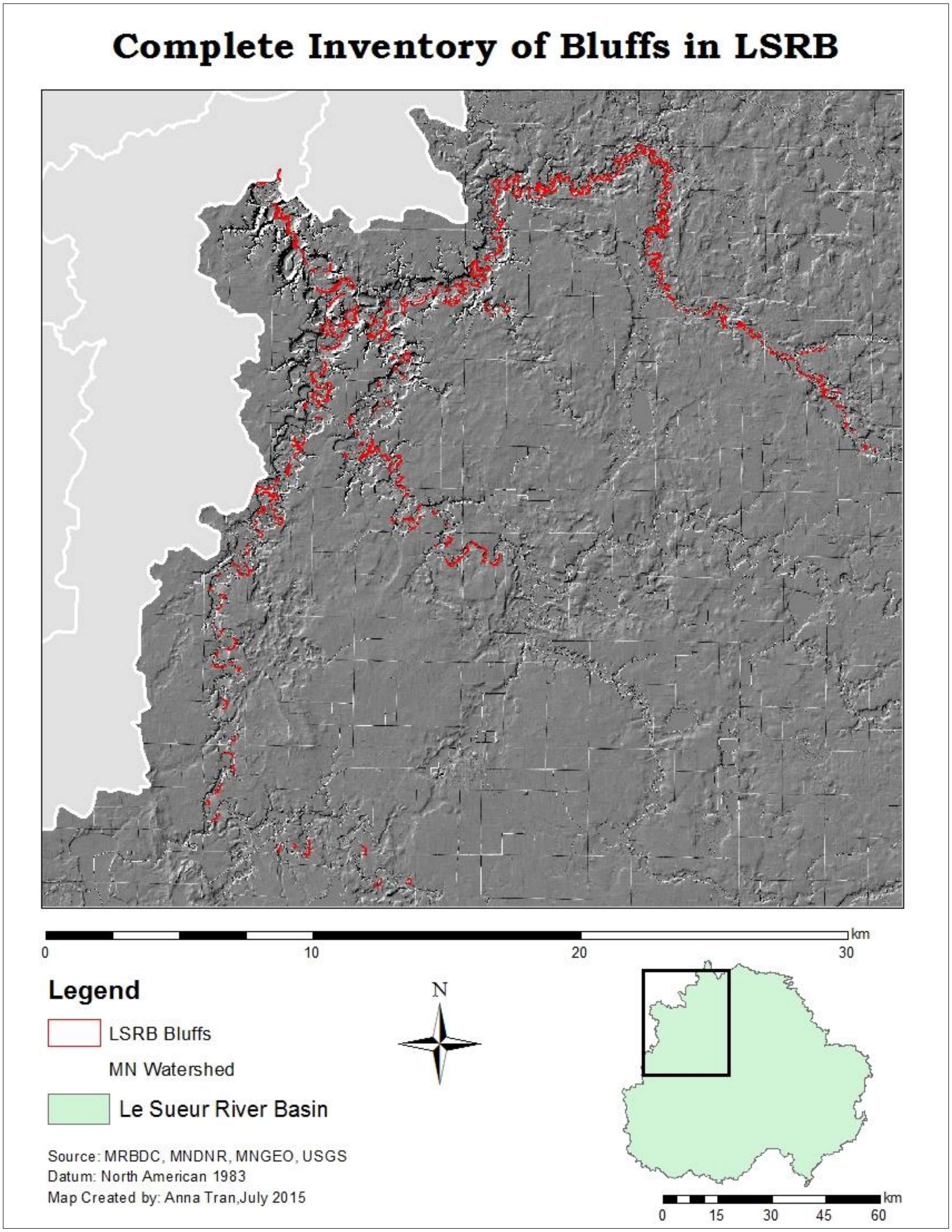

Figure 13. Derived from the spatial analysis minus and slope degree analysis, 376 bluffs in the LSRB were identified as areas with the largest amount of erosion from 2005 to 2012.

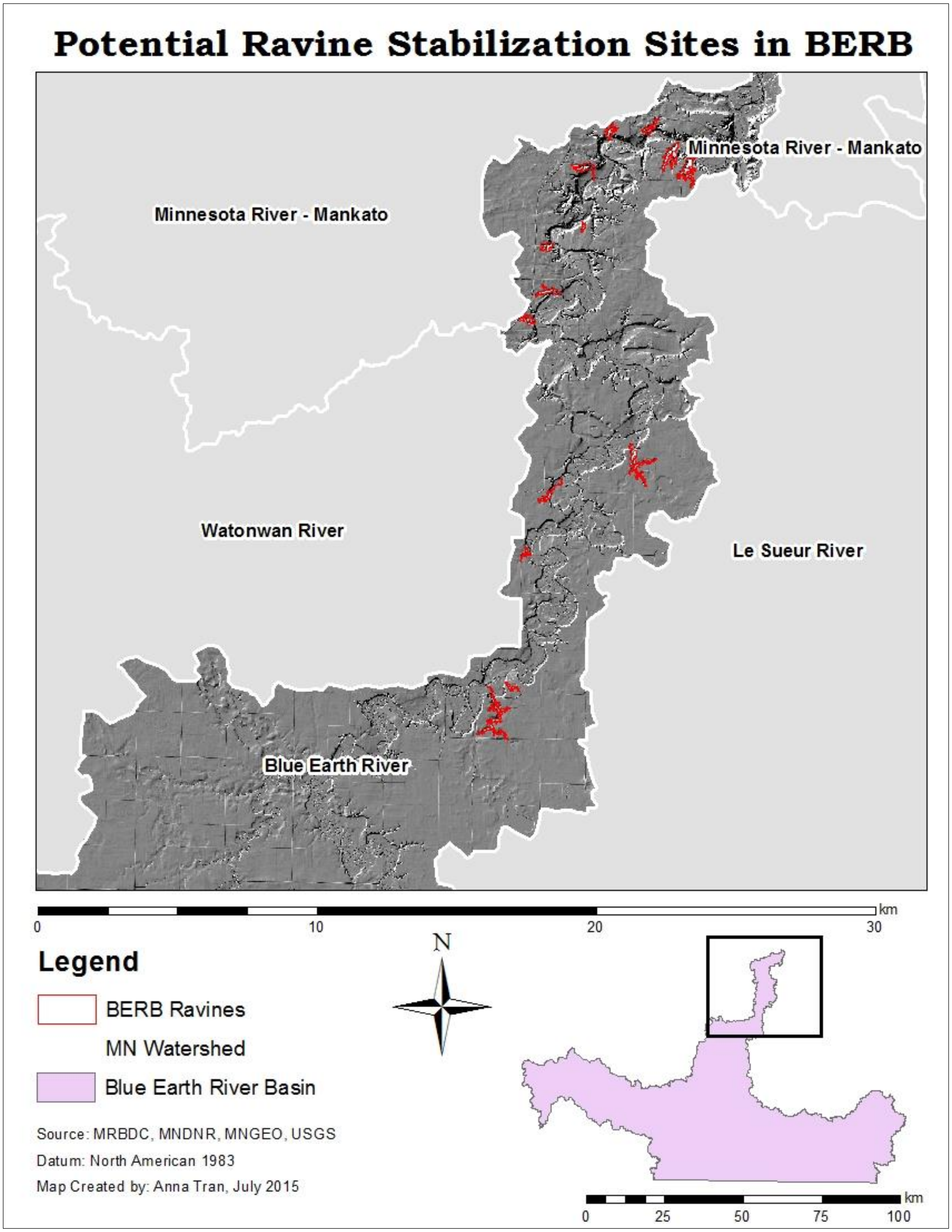

Figure 14. Fourteen ravines were considered as potential ravine stabilization sites in the BERB. These sites were narrowed from the previous 59 sites in Figure 10 using socioeconomic parameters such as accessibility, connectivity, proximity, visibility, and threat to rivers, roads, and buildings.

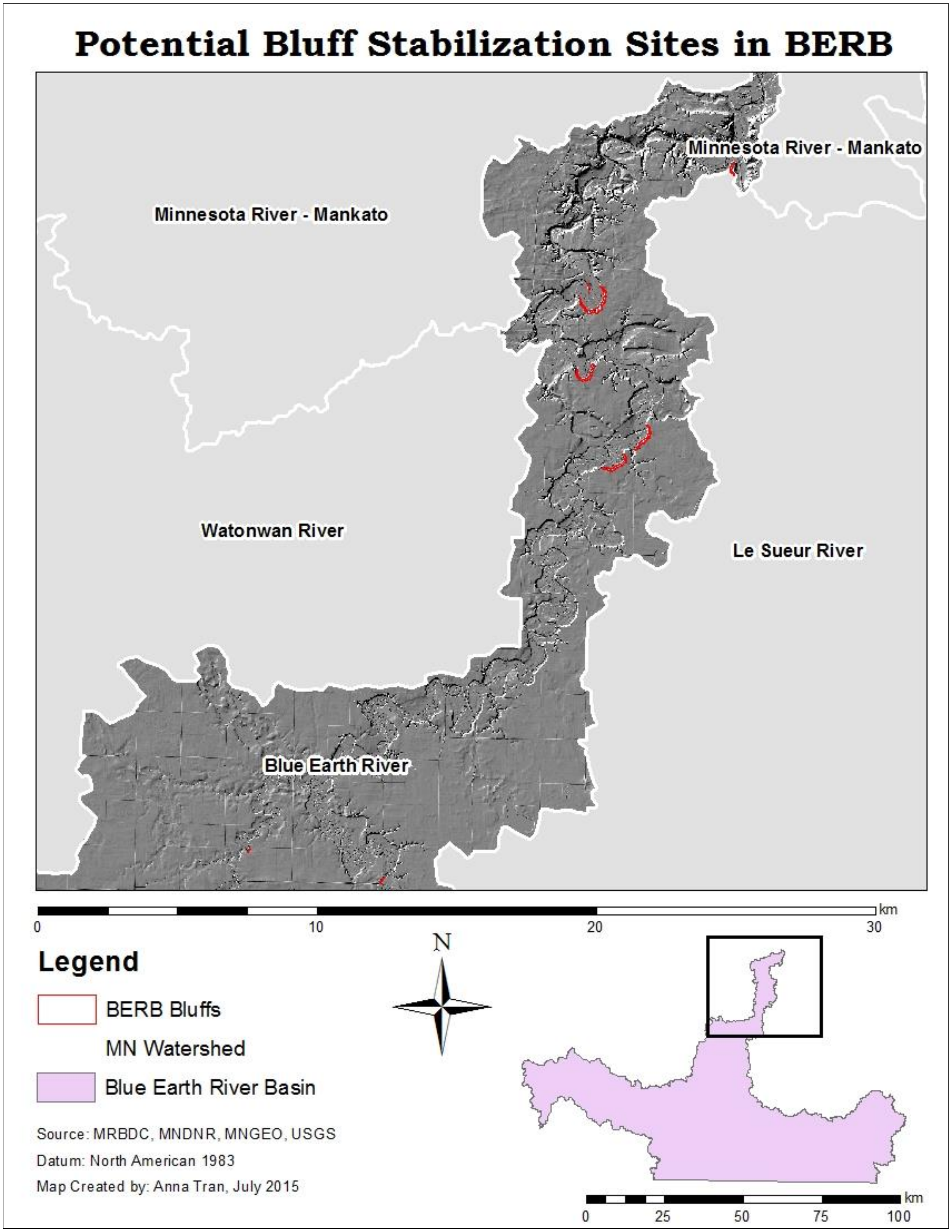

Figure 15. Ten bluffs were considered as potential bluff stabilization sites in the BERB. These sites were narrowed from the previous 96 sites in Figure 11 using socioeconomic parameters such as accessibility, connectivity, proximity, visibility, and threat to rivers, roads, and buildings.

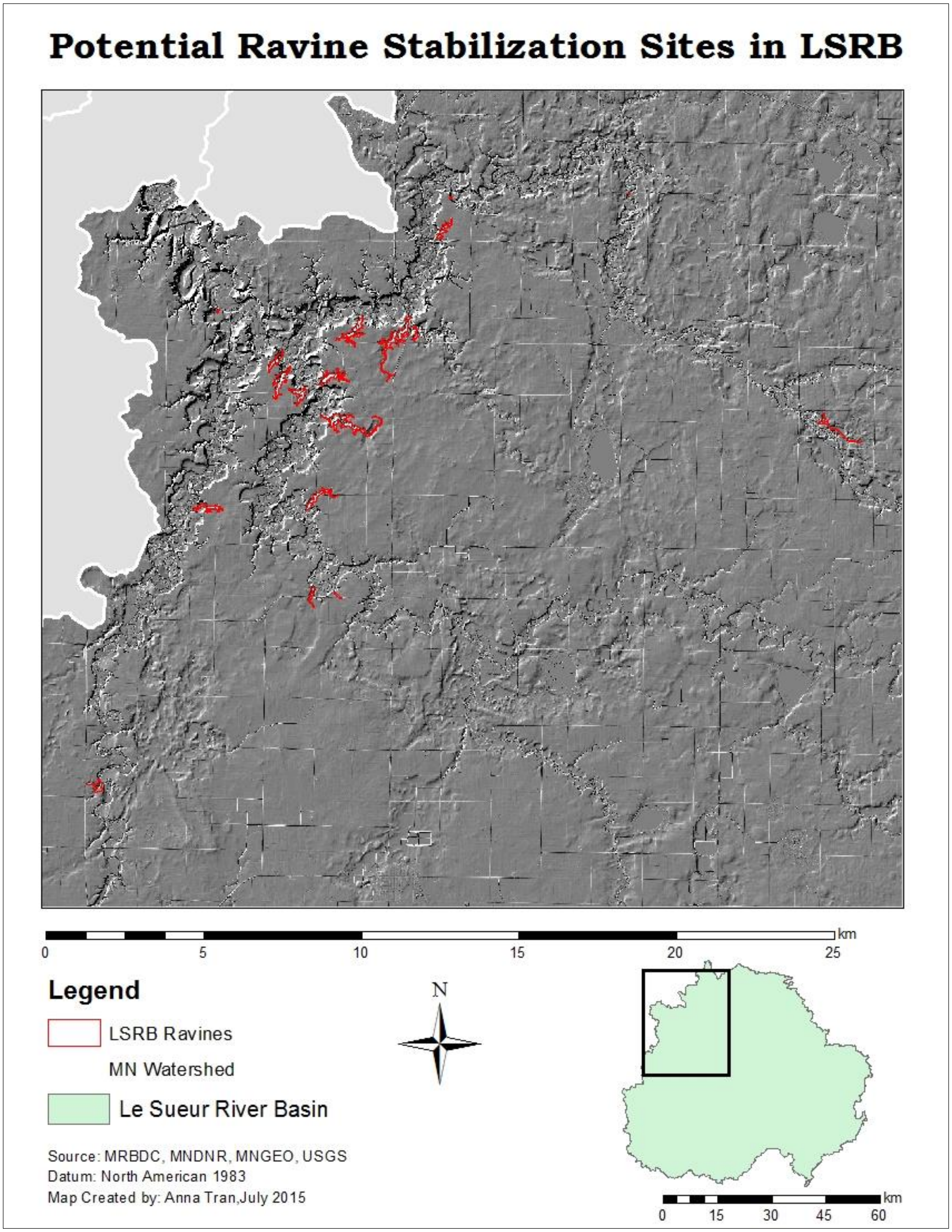

Figure 16. Eighteen ravines were considered as potential ravine stabilization sites in the LSRB. These sites were narrowed from the previous 62 sites in Figure 12 using socioeconomic parameters such as accessibility, connectivity, proximity, visibility, and threat to rivers, roads, and buildings.

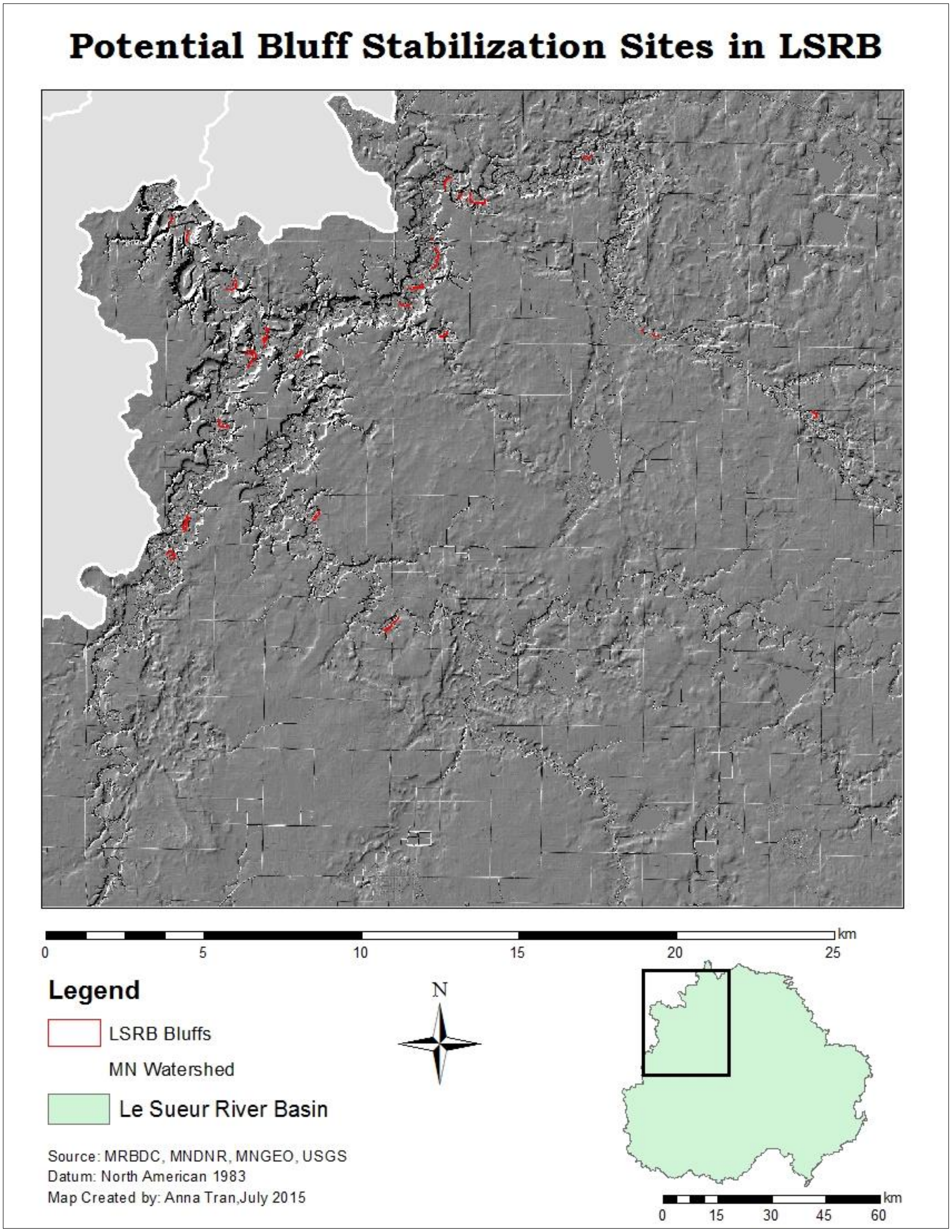

Figure 17. Twenty-nine bluffs were considered as potential bluff stabilization sites in the LSRB. These sites were narrowed from the previous 376 sites in Figure 13 using socioeconomic parameters such as accessibility, connectivity, proximity, visibility, and threat to rivers, roads, and buildings.

Table 1. Final ravines in the BERB watershed in GIS polygon form to complement Figure 14. This table represents the parameters and characteristics of each of the final ravines narrowed down based on the scientific and socioeconomic criteria. OID indicates object ID, SM indicates soil material, ST indicates soil texture, PIB indicates proximity to infrastructure (buildings) measured in meters, PIR indicates proximity to infrastructure (roads) measured in kilometers, LU indicates land use symbol, GPS indicates Global Positioning System measured in decimal degrees. Every site on this list is connected to the river, has stream visibility within 7.62 m (25 feet), has road visibility within 7.62 m (25 feet), has road accessibility, and is a threat to infrastructure. Under soil material, GL represents gray lacustrine, and GT represents gray till. Under soil texture, FL represents fine-loamy, FS represents fine-silty, CL represents coarse-loamy. Under proximity to roads, ADJ represents adjacent. Under land use symbols, C represents cultivated land, DF represents deciduous forests, EXP represents exposed soils, sandbars, and sand dunes; F represents farmsteads and rural residences, G represents grasslands, OR represents other rural developments, RR represents rural residential development complex; and W represents water. For a list of complete data table acronyms, see Appendix A.

OID	SM	ST	PIB	PIR	LU	GPS (DD)	SL (m)	SA (m^2)
17	GL; GT	FL; FS	13.761895	Adjacent	C; DF; F; G; OR; W	-94.148563 43.952183	11575.47178	276409.8636
18	GT	FL	10.375201	Adjacent	C; DF; F; G	-94.142069 43.958632	1819.141545	41513.0014
24	GL	FS	1.778051	Adjacent	C; DF; EXP; F; G; W	-94.136045 44.002354	1962.869858	46387.64751
31	GL	FS	0.286551	Adjacent	C; DF; F; G; W	-94.126506 44.020440	3916.570452	78155.15463
36	GL; GT	FL; FS	4.41538	Adjacent	C; DF; EXP; F; G; W	-94.088953 44.033890	8646.88751	218527.0506
41	GL; GT	CL; FL	4.328117	0.047155	C; DF; EXP; G; W	-94.136578 44.077666	2329.388662	85679.10991
43	GT	FL	26.036011	0.192837	C; DF; EXP; F; G; W	-94.127215 44.087093	2907.536983	109213.8721
46	GL; GT	CL; FL	15.612847	0.210693	C; DF; F; G; GTD; OR; W	-94.128738 44.101380	2282.90442	86352.11914
49	GT	FL	3.857892	Adjacent	C; DF; RR; W	-94.112592 44.108038	1074.170959	25451.50163
53	GL; GT	CL; FL	4.08169	Adjacent	C; DF; G; W	-94.111419 44.127284	3952.45448	163951.605
54	GL; GT	FL; FS	0.678012	Adjacent	C; DF; F; G; OR; W	-94.066528 44.127563	6585.074531	250364.4391
55	GT	FL	1.102187	0.116197	C; DF; F; G; OR; W	-94.073894 44.132556	5641.775664	215730.2213
59	GL	CL	1.464002	Adjacent	C; DF; F; W	-94.101854 44.138495	3164.685434	95800.77032
60	GL; GT	CL; FL	118.459167	0.287588	C; DF; G; W	-94.084683 44.139131	2911.901734	83317.25523

Table 2. Final bluffs in the BERB watershed in GIS polygon form to complement Figure 15. This table represents the parameters and characteristics of each of the final bluffs narrowed down based on the scientific and socioeconomic criteria. OID indicates object ID, SM indicates soil material, ST indicates soil texture, PIB indicates proximity to infrastructure (buildings) measured in meters, PIR indicates proximity to infrastructure (roads) measured in kilometers, LU indicates land use symbol, GPS indicates Global Positioning System measured in decimal degrees. Every site on this list is connected to the river, has stream visibility within 7.62 m (25 feet), has road visibility within 7.62 m (25 feet), has road accessibility, and is a threat to infrastructure. Under soil material, GL denotes gray lacustrine, and GT denotes gray till. Under soil material, GL represents gray lacustrine, and GT represents gray till. Under soil texture, FL represents fine-loamy, and F represents fine texture. Under proximity to roads, ADJ represents adjacent. Under land use symbols, C represents cultivated land, DF represents deciduous forests, EXP represents exposed soils, sandbars, and sand dunes; F represents farmsteads and rural residences, G represents grasslands, OR represents other rural developments, RR represents rural residential development complex; and W represents water. For a list of complete data table acronyms, see Appendix A.

OID	SM	ST	PIB	PIR	LU	GPS (DD)	SL (m)	SA (m^2)
2	GL	F	70.334838	0.143295	C; DF; W	-94.197355 43.861698	992.976 113	15113. 56005
3	GT	FL	0.786365	ADJ	C; DF; F; G; OR; W	-94.183114 43.865779	1038.55 5994	13966. 46647
10	GT	FL	25.600785	ADJ	C; DF; F; W	-94.198816 43.896336	639.994 847	6304.9 13302
12	GL	F	42.606529	0.015776	C; DF; G	-94.258591 43.905212	396.164 726	3772.6 87286
62	GT	FL	10.821858	ADJ	C; DF; EXP; F; W	-94.095782 44.030881	2721.13 6435	77270. 31447
67	GT	FL	0.82921	ADJ	C; DF; EXP; OR; W	-94.082710 44.040013	2867.84 5517	73364. 95201
73	GT	FL	0.923278	ADJ	C; DF; F; G; OR; W	-94.110090 44.058863	2801.66 3323	89799. 74949
80	GT	FL	7.02391	0.063353	C; DF; EXP; F; G; W	-94.104984 44.081761	4698.19 8636	150184 .8847
81	GT	FL	15.974285	0.10904	DF; G; OR; W	-94.110160 44.088315	898.440 822	6545.6 50859
91	GT	FL	6.139194	0.061656	C; DF; F; G; GP; W	-94.046989 44.127679	1144.26 8836	27597. 8997

Table 3. Final ravines in the LSRB watershed in GIS polygon form to complement Figure 16. This table represents the parameters and characteristics of each of the final bluffs narrowed down based on the scientific and socioeconomic criteria. OID indicates object ID, SM indicates soil material, ST indicates soil texture, PIB indicates proximity to infrastructure (buildings) measured in meters, PIR indicates proximity to infrastructure (roads) measured in kilometers, LU indicates land use symbol, GPS indicates Global Positioning System measured in decimal degrees. Every site on this list is connected to the river, has stream visibility within 7.62 m (25 feet), has road visibility within 7.62 m (25 feet), has road accessibility, and is a threat to infrastructure. Under soil material, GL represents gray lacustrine, and GT represents gray till. Under soil texture, FL represents fine-loamy, FS represents fine-silty, and F represents fine. Under proximity to roads, ADJ represents adjacent. Under land use symbols, C represents cultivated land, DF represents deciduous forests, F represents farmsteads and rural residences, G represents grasslands, GTD represents grassland-shrub-tree (deciduous), RR represents rural residential development complex; UC represents unclassified, and W represents water. For a list of complete data table acronyms, see Appendix A.

OID	SM	ST	PIB	PIR	LU	GPS (DD)	SL (m)	SA (m^2)
7	GL; GT	FL; FS	59.04687	ADJ	C; DF; F; G; W	-94.073410 43.952645	2058.66598	59040.78693
11	GL	F	6.312145	ADJ	C; DF; G	-93.981063 44.008420	741.631368	15174.25001
12	GL	F	6.303364	ADJ	C; DF; F; G	-93.990245 44.008327	1799.135839	32978.23627
19	GL; GT	F; FL	5.928843	ADJ	C; DF; F; G	-94.032120 44.032584	3520.426022	84120.5791
21	GL; GT	F; FL	14.1705	ADJ	C; DF; F; G; GTD; UC	-93.989522 44.035737	3675.438705	112225.6917
25	GL; GT	F; FL	1.530048	ADJ	C; DF; F; G; W	-93.982014 44.058257	9589.443124	315477.3261
26	GL	F	16.69478	ADJ	C; DF; F; G	-93.788865 44.058880	4132.059301	56046.5484
29	GT	FL	15.38904	0.014375	C; DF; G; RR	-93.995152 44.065588	2837.547128	92083.1483
35	GL; GT	F; FL	2.992284	ADJ	C; DF; F; G	-93.984487 44.070421	4874.862344	127739.3735
36	GL; GT	F; FL	6.391061	0.234067	C; DF; F	-94.003384 44.069443	4409.842221	152906.4971
38	GL; GT	F; FL	23.95923	0.010934	C; DF; F; G	-94.005040 44.075018	2535.857705	76745.0793
39	GL	F	1.880579	0.12389	C; DF; F; G	-93.950288 44.082639	1628.666377	25281.39821
42	GL	F	7.512465	ADJ	C; DF; F; G; RR; UC	-93.956979 44.082702	10070.89994	272916.9974

Table 3 (Continued)

OID	SM	ST	PIB	PIR	LU	GPS (DD)	SL (m)	SA (m^2)
			3.694		C; DF; F;	-93.974414	5653.6	166278.2
43	GL; GT	F; FL	7	ADJ	G; UC	44.083816	57055	358
			45.83	0.025	C; DF; F;	-94.028793	453.94	7085.107
44	GT	FL	26	98	W	44.088741	2508	659
			10.37		C; DF; F;	-93.940438	3165.4	79026.72
52	GL	F	401	ADJ	G; W	44.112485	59588	191
			14.55	0.082	C; DF; F;	-93.937118	359.69	4752.806
54	GL	F	524	538	W	44.121665	6459	551
			20.81			-93.866640	168.15	1224.469
56	GT	F	481	ADJ	C; DF	44.123352	7455	869

Table 4. Final bluffs in the LSRB watershed in GIS polygon form to complement Figure 17. This table represents the parameters and characteristics of each of the final bluffs narrowed down based on the scientific and socioeconomic criteria. OID indicates object ID, SM indicates soil material, ST indicates soil texture, PIB indicates proximity to infrastructure (buildings) measured in meters, PIR indicates proximity to infrastructure (roads) measured in kilometers, LU indicates land use symbol, GPS indicates Global Positioning System measured in decimal degrees. Every site on this list is connected to the river, has stream visibility within 7.62 m (25 feet), has road visibility within 7.62 m (25 feet), has road accessibility, and is a threat to infrastructure. Under soil material, GL represents gray lacustrine, and GT represents gray till. Under soil texture, FL denotes fine-loamy, VF denotes very-fine, and F represents fine. Under proximity to roads, ADJ represents adjacent. Under land use symbols, C represents cultivated land, DF represents deciduous forests, EXP represents exposed soils, sandbars, and sand dunes; F represents farmsteads and rural residences, G represents grasslands, GP represents gravel pits and open mines, GTD represents grassland-shrub-tree (deciduous), OR represents other rural developments, RR represents rural residential development complex; U/I represents urban and industrial; W represents water; WET represents wetlands. For a list of complete data table acronyms, see Appendix A.

OID	SM	ST	PIB	PIR	LU	GPS (DD)	SL (m)	SA (m^2)
5	GT	FL	6.7850 25	ADJ	C; DF; F; G; OR; WET	-94.002117 43.900376	979.421 932	7309.73 5925
6	GL; GT	F; VF; FL	38.412 902	ADJ	C; DF; F; G; W	-94.042434 43.900690	671.032 378	5830.33 0703
40	GL	F	91.242 682	ADJ	C; DF; G; GTD	-93.958459 44.000091	1645.38 2013	17958.8 3719
67	GT	FL	22.038 293	ADJ	C; DF; EXP; F; G; W	-94.048416 44.018885	1106.77 2468	13559.4 6821
77	GT	FL	47.575 072	ADJ	C; DF; F	-94.041277 44.027748	729.919 712	6537.68 0799
79	GT	FL	1.2652 05	ADJ	C; DF; EXP; F	-94.040440 44.028120	1308.48 4979	22312.9 1923
80	GT	FL	1.0663 49	0.079 42	C; DF; EXP; F; G	-93.988787 44.030780	789.317 183	19477.3 8488
121	GT	FL	4.4519 51	ADJ	C; DF; F; G	-94.027069 44.055650	1080.50 356	8360.79 4169
126	GL	F	1.0334 72	0.010 06	C; DF; F	-93.791835 44.061129	653.705 771	6431.79 7008
170	GT	FL	5.8270 69	ADJ	C; DF; G; GP; RR	-94.014454 44.076318	1829.44 2251	46537.7 7851
172	GT	FL	2.6055 06	ADJ	C; DF; F	-93.996065 44.077088	893.271 205	8649.72 7406

Table 4 (Continued)

OID	SM	ST	PIB	PIR	LU	GPS (DD)	SL (m)	SA (m^2)
182	GT	FL	2.66202	0.049787	C; EXP; F; G; W	-94.010414 44.080010	613.916733	5309.23232
187	GT	F	6.600403	ADJ	DF; G; U/I	-93.855519 44.082910	493.292544	2994.61415
190	GL	F	7.935309	ADJ	DF; G; RR	-93.938960 44.082493	756.994089	10536.92468
195	GT	F	1.837921	0.031193	C; DF; U/I	-93.860577 44.084401	264.403538	1762.619854
200	GT	FL	1.900255	0.076966	C; DF; F; G; W	-94.009175 44.082468	1255.07942	11897.30787
224	GT	FL	26.372313	ADJ	C; DF; G; RR	-93.954268 44.090801	1083.350391	7578.88176
241	GL	F	0.858162	ADJ	C; DF; F; G	-93.949617 44.096031	1615.729443	17898.331
243	GT	FL	8.163896	0.002119	C; DF; W	-94.022035 44.095423	1199.109274	15700.56422
258	GL	F	50.791427	ADJ	C; DF; W	-93.942753 44.102463	662.682074	5479.913236
263	GL	F	36.038137	ADJ	C; DF; F; G; W	-93.941896 44.105994	1040.094	8894.165989
269	GL	F	45.889803	0.024236	C; DF; F; W	-93.944914 44.109758	272.612119	1855.325193
278	GT	FL	12.67013	0.020484	C; DF; F; W	-94.041723 44.109898	745.667865	7182.630012
291	GT	FL	2.643453	0.017402	C; DF; F; G; W	-94.047958 44.114150	791.058771	7588.255134
301	GL	F	6.281668	0.077926	C; DF; G	-93.924239 44.120410	876.031948	7781.252654
306	GL	F	4.089903	ADJ	DF; RR; W	-93.933521 44.122288	486.663727	4815.430274
308	GL	F	24.374134	ADJ	C; DF; RR; W	-93.929657 44.121871	708.903553	7392.612922
339	GL	F	2.619058	ADJ	C; DF; F; G; W	-93.939176 44.126507	986.979432	7662.958231
363	GT	F	41.404069	ADJ	C; DF; F; G	-93.883676 44.133100	851.675555	5563.829859

Objective 2: Review of hydrological and sediment transport models to provide a foundation for natural resources management within watersheds.

Due to terrain, difficulty measuring, and high costs, there is a lack of monitoring and gauging data for site specific ravines and bluffs within the BERB and the LSRB, therefore, models cannot be used to estimate sediment load reductions until such data is acquired. Over thirty models were considered, however, seventeen erosion and sediment transport models, both empirically and physics-based were reviewed based on applicability for future application of estimating sediment loss for ravines and bluffs in an agriculturally dominated region.

Empirically based models usually require less data and are easier to apply, particularly over large areas (Merritt et al., 2003). The drawback of empirical models are that they lack specificity and does not incorporate mechanism (Merritt et al., 2003). Despite this, empirical models can garner results that are reasonably accurate and reflect the underlying process generating erosion and sediment load. Physics-based models attempt to capture the physics of the system and if specified properly, can be used to provide insight into the system's behavior (Merritt et al., 2003). Physically based models can be manipulated for conducting "what if" scenarios to investigate the effects of management practices. The drawback for physically based models are that it can be so complex that it is difficult to determine how to translate management practices into specific changes in the model parameter values or physical processes simulated by the mathematics in the model (Merritt et al., 2003). Moreover, physics-based models require that the physics of the system be specified properly and generally requires a large amount of data to both parameterize and validate the model (Merritt et al., 2003).

The model review encompasses models pertaining to soil loss and watershed management. They vary in terms of scale, continuity, inputs and outputs. The model review summarizes the history of the model, the objectives and intentions for the model, the model structure, the cost, the input parameters, the output, the predictive accuracy, as well as the advantages and limitations. Once sites are selected for restoration, monitoring will begin to gather the necessary parameters for the model simulations.

Universal Soil Loss Equation Family

Universal Soil Loss Equation (USLE)

The Universal Soil Loss Equation (USLE) was developed in the 1970s by the United States Department of Agriculture (USDA) to address ongoing soil erosion issues since the Dust Bowl (Wischmeier and Smith, 1978; Charlton, 2008; USDA, 2009). The model has undergone extensive research and modifications (e.g. MUSLE, RUSLE1, RUSLE2) (Merritt et al., 2003). The model was intended to estimate the amount of soil erosion and the impact of the use of alternative cropping management practices and/or conservation practices for individual storm events and large areas (Wischmeier and Smith, 1978; Merritt et al., 2003; USDA, 2009; Arekhi et al., 2010). USLE is structured such that the empirical overland flow or sheet rill erosion regression is based primarily on observations (Merritt et al., 2003; Charlton, 2008). The equation to represent the data is:

$$A = R \times K \times L \times S \times C \times P$$

where A is the estimated soil loss per unit area, R is the rainfall erosivity factor, K is the soil erodibility factor, L is the slope-length factor, S is the slope-steepness factor, C is the cover and management factor, P is the support practice factor (Wischmeier and Smith, 1978; Merritt et al., 2003; Charlton, 2008).

The input data are: annual rainfall, an estimation of soil erodibility, land cover information, and topographic information (Merritt et al., 2003). The output is the annual estimate of soil erosion rom hillslopes, which are both spatially and temporally lumped together (Merritt et al., 2003). The advantages of USLE are that it is easy to use, and it requires minimal data (Merritt et al., 2003). The limitations, however, are that it is not responsive and only provides annual estimate of soil loss. It ignores the processes of rainfall runoff and how these processes affect erosion as well as the heterogeneities in inputs such as vegetation cover and soil types (Merritt et al., 2003). The model is also limited by the fact that it is not event based, and as such cannot identify those events most likely to result in large scale erosion, moreover, gully erosion and mass movement are ignored and the deposition of sediment is not considered to occur in the modelled area (Zhang et al., 1995; Merritt et al., 2003; Charlton, 2008). Improvements, modifications, and revisions to the basic format of USLE were made to make the model more process-based (Merritt et al., 2003).

Modified Universal Soil Loss Equation (MUSLE)

Improvements from the basic USLE to MUSLE is that MUSLE predicts soil loss better than USLE (Kinnell and Risse, 1998) based on the rainfall erosivity factor for an event. In addition, MUSLE is used for computing the amount of potential soil erosion and sediment yield (Mishra et al., 2006; Arekhi et al., 2010). The inputs of MUSLE that differ from USLE is the soil erodibility factor *K* and rainfall factor *R*. *K* factor values by USLE-M varied 1.4 to 3.9 times, the USLE K values under simulated rainfall (Kinnell and Risse, 1998; Sepaskhah & Molodi, 2003). MUSLE replaces USLE's rainfall factor with a runoff factor (Arekhi et al., 2010). Outputs from MUSLE are the estimate of soil loss from *K* values for a single storm event (Kinnell and Risse, 1998; Sepaskhah & Molodi, 2003). The predictive accuracy of MUSLE is that it increases sediment yield prediction accuracy and it eliminates the need for delivery ratios (Arekhi et al., 2010). Advantages of MUSLE over USLE is that it provides a more complex representation of processes than USLE as it more directly considers the effect of runoff on erosion with changes to the *R* and *K* factor for a single rain event (Kinnell and Risse, 1998; Merritt et al., 2003). MUSLE is also easier to apply because the output data for this model can be determined at the watershed outlet (Arekhi et al., 2010).

Revised Universal Soil Loss Equation 1 (RUSLE1)

Improvements from USLE is that RUSLE1 continues the basic form of USLE, although the equation used to arrive at the factor values have been modified (Lane et al., 1992; Merritt et al., 2003). The RUSLE1 version can be downloaded for free (Appendix B). The differing inputs are the change in the length of slope *L* factor which enables the prediction of soil loss due to overland flow in three-dimensional terrain slopes (Ryan and McKenzie, 1997; Merritt et al., 2003). The output of RUSLE1 is the prediction of soil loss due to overland flow in three-dimensional terrains with convergent and divergent slopes (Ryan and McKenzie, 1997; Merritt et al., 2003). In addition, the rate of erosion is determined by the use of satellite imagery (Kamalaudin et al., 2013). The advantages of RUSLE1 over USLE is that it expands information on soil erodibility (Merritt et al., 2003). RUSLE1 also has the capacity to estimate the *C* factor from information on vegetation form, decay, tillage practices rather than from experimental plot data as used in USLE (Merritt et al., 2003; NRCS, 2013). The limitations of RUSLE1, however, are that it lacks sediment characteristics and the data is not on a daily basis (USDA, 2010).

Revised Universal Soil Loss Equation 2 (RUSLE2)

RUSLE2 is the enhancement of USLE and RUSLE1 which improves the approach for estimating soil loss, has a modern graphical user interface, and easily accommodates the conversion between customary US and SI (metric) units (USDA, 2010; NRCS, 2013). It also improves the cover-management subfactor relationships, added a new ridge subfactor, and the deposition equations have been extended to consider sediment characteristics and how deposition changes these characteristics (NRCS, 2013). The RUSLE2 version can be downloaded for free (Appendix B). RUSLE2 uses the same equation as USLE and RUSLE1, however the difference in input is that each value used are daily values presenting the long-term average conditions for that day (USDA 2010; NRCS, 2013). The outputs which differ in RUSLE2 are that it predicts and estimates the rates of rill and interrill soil erosion caused by rainfall and overland flow (USDA 2010). The advantages of RUSLE2 over RUSLE1 is that it describes specific field conditions and sediment characteristics and uses that description to compute erosion and estimate rates of erosion (USDA, 2010). It is also easier to obtain daily inputs for RUSLE2 (NRCS, 2013). The limitations of RUSLE2, however, are that it does not replicate field processes nor does it model vegetation growth (USDA, 2010).

Better Assessment Science Integrating Point and Nonpoint Sources Family

Better Assessment Science Integrating Point and Nonpoint Sources (BASINS)

Originally introduced in 1996, BASINS was developed by the United States Environmental Protection Agency (USEPA) to assist in watershed management and Total Maximum Daily Load (TMDL) development by integrating environmental data, analysis tools, and watershed and water quality models (Whittemore and Beebe, 2000; EPA, 2015a). Since inception, there have been updates and modifications to this model, as well as models based off of BASINS and incorporated into BASINS (Whittemore and Beebe, 2000; EPA, 2015a). BASINS was intended to be a multipurpose environmental analysis system, with the intention of helping regional, state, and local agencies perform watershed and water quality based studies specifically with TMDL utility as the primary reason (Whittemore and Beebe, 2000; EPA, 2015a). It integrates GIS, and through GIS, BASINS has the flexibility to displace and integrate a wide range of information (e.g. land use, point source discharges, and water supply withdrawals) at scales chosen by the user (EPA, 2015a). It builds upon federal databases of water quality conditions and point source loadings from numerous parameters (Whittemore and Beebe, 2000).

With any first generation model, there are limitations. Technical and philosophical concerns related to default data usage, seamless generation of model input files, and the failure of some utilities to work properly suggests that serious problems may still exist (Whittemore and Beebe, 2000). Moreover, limitations of the default datasets in BASINS for example: watersheds, large scale data is beyond resolution capabilities; for soils, positional accuracy between physical boundaries and digitized locations is unknown; for streams, stream locations are missing, disconnected or flow direction is incorrect (Whittemore and Beebe, 2000). BASINS has improved and grown through scientific enhancements as TMDL developers became more familiar with modeling requirements and GIS based approaches (Whittemore and Beebe, 2000). Since 1996, with BASINS v. 1.0, there have been five updates and modifications: BASINS 2.0 (1998); BASINS 2.1 (2000); BASINS 3.0 (2000) where SWAT was introduced; BASINS 4.0 (2001); and the current release BASINS 4.1 (2013) (Whittemore and Beebe, 2000; EPA, 2015a). BASINS 4.0 is the first BASINS version to be based on a non-proprietary, open source GIS foundation (EPA, 2015a). The core design of BASINS 4.0 is to complement and interoperate with enterprise and full featured GIS systems, and it can import and export projects from ArcView and ArcGIS, which means that the user can access features available in both systems that are not available in BASINS 4.0 (EPA, 2015a). BASINS 4.1 is built upon the latest stable release of the non-proprietary, open source GIS foundation, and the automatic watershed delineation tools have been updated to use TauDEM version 5 from Utah State University (EPA, 2015a). The major functionality of two utilities, GenScn and WDMUtil, have been incorporated into the BASINS user interface, and it now includes DFLOW, a tool to estimate design stream flows for use in water quality studies (EPA, 2015a). The latest version of BASINS can be downloaded for free (Appendix B).

Soil and Water Assessment Tool (SWAT)

SWAT is a conceptual basin-scale, continuous time model for long-term assessment that was developed in the early 1990s to assist water resource managers in assessing the impacts of management and climate on water supplies and nonpoint source pollution in watersheds and large river basins (Arnold et al., 1998; Sharpley et al., 2002; Jha et al., 2004; Arnold and Fohrer, 2005; Li et al., 2012). It is the product of a culmination of 30 years of model development within the USDA's Agricultural Research Service (Arnold and Fohrer, 2005). It was developed with the intention to 'scale-up' past field scale models to large river basins by predicting and assessing the impact of land management decisions on water quality (Arnold et al., 1998; Sharpley et al., 2002; Arnold and Fohrer, 2005; Ye et al., 2011). The primary objectives were to stress 1) climate and management impacts, 2) water quality loadings and fate, 3) flexibility in basin discretization, and 4) continuous time simulation (Arnold and Fohrer, 2005). The model structure simulates the hydrological process based on the spatial characteristics of climate, topography, soil properties, land use and management practices; uses a semi-distributed approach to represent the spatial variability of the watershed by subdividing it into a number of subbasins (Jha et al., 2004; Li et al., 2012). SWAT is physically based, computationally efficient, and capable of continuous simulation over long periods (Jha et al., 2004). The model is based on the water balance equation:

$$\mathrm{SWt} = \mathrm{SW0} + \sum_{i=0}^{t} (Rday - Qsurf - Ea - Wseep - Qgw)$$

where: SW_t is the final soil water content (mm), SW_0 is the initial soil water content on day *i* (mm), *t* is the time (days), Q_{surf} is the amount of precipitation/surface runoff on day

i (mm), E_a is the amount of ET on day i (mm), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm), Q_{gw} is the amount of return flow on day i (mm) (Ye et al., 2011). The latest version of SWAT can be downloaded for free (Appendix B).

The SWAT interface creates and populates a database to store the input parameters of the model (Di Luzio et al., 2002). The input parameters are: soil, weather, subbasin or land use soil item, stream reach, groundwater, water use, management, pond, and lake; land management input parameters include planting, harvesting, tillage operation, irrigation, and nutrient and pesticide applications (Di Luzio et al., 2002). The user sets up the simulation control codes, and the execution of the model starts the simulation after an optional validity of all necessary input files (Di Luzio et al., 2002). The output creates tables that can be exported in order to be carted, mapped, and statistically evaluated in the comparison with observed data (Di Luzio et al., 2002). SWAT allows the user to interactively perform calibration on the model simulations; user can target the most sensitive input parameters of the model, set variations, active them for target subbasins and land use soil combinations, and run the model (Di Luzio et al., 2002). Moreover, it is widely used in rural and suburban watersheds with over 800 related research and peer review articles on the effectiveness and accuracy (Arnold et al., 1998; Ye et al., 2011; Arnold, 2013; Jeong et al., 2013).

The advantages of SWAT is that it does not require calibration (calibration is not possible on ungauged basins) (Arnold and Fohrer, 2005). SWAT uses readily available inputs for large areas (Arnold and Fohrer, 2005). It is computationally efficient to operate on large basins in a reasonable time (Arnold and Fohrer, 2005), and predicts long term impacts in large basin (Li et al, 2012). SWAT is a sensitive model that operates on a daily time step at basin scale (Jeong et al., 2010; 2013) and is continuous and capable of simulating long periods for computing the effects of management change (Arnold and Fohrer, 2005). It also aids in assessing the efficiency of Best Management Practices (BMPs) and alternative management policies (Arnold and Fohrer, 2005).

The limitations of SWAT are that it cannot reproduce high runoff peaks associated with intense storm events (Inamdar, 2006). It cannot replicate snow accumulation and melt accurately (Inamdar, 2006). Soil and climate variability greatly affects watershed water balance of the SWAT model in some semi-arid regions (Muttiah and Wurbs, 2002; Ye et al., 2011), and when the scale of the soil map changed from 1:250000 to 1:24000, it resulted in a large variation in average soil water storage (Chaplot, 2005; Ye et al., 2011). Hydrological models have relatively strong sensitivity to soil physical properties such as moist bulk density, available water capacity, and saturated hydraulic conductivity (Lenhart et al., 2002; Ye et al., 2011).

Ephemeral Gully Erosion Model Family

Ephemeral Gully Erosion Model (EGEM)

EGEM is a modification of the Agricultural Research Service's Ephemeral Gully Erosion Estimate computer model (developed by Dr. John M. Laflen) to meet the Natural Resource Conservation Service (NRCS) needs (Woodward, 1999). It was specifically developed to predict soil loss by ephemeral gully erosion (Nachtergaele et al., 1999). EGEM is structured by two major components: hydrology and erosion. The hydrology component uses the NRCS curve number, drainage area, watershed flow length, average watershed slope, and 24-hr rainfall and standard NRCS temporal rainfall distributions to estimate peak discharge and rates and runoff volumes (Woodward, 1999). EGEM takes into account detachment of soil due to shear of flowing water, sediment transport capacity, and changing channel dimensions (Nachtergaele et al., 1999).

The input data is grouped into four main categories: identification information, watershed data, soil data, and rainfall data (Woodward, 1999). Some parameters include: drainage area, watershed length, concentrated flow length, watershed slope, concentrated flow slope, curve number, soil class, channel erodibility factor, critical shear stress, maximum gully depth, gully length and width, bulk density, particle diameter, particle specific gravity, rain distribution type, 24-hour rainfall depth, and tillage practice, with the key parameter in determining the ephemeral gully volume is the gully length (Nachtergaele et al., 1999). The output is an estimate of peak discharge and rates of runoff volumes and computes the width and depth of the ephemeral gully for a single 24-hour storm or average annual conditions (Woodward, 1999). It is reported in total short tons and as a voided area representing the surface area of the gully. For average annual erosion estimates, both seasonal and annual values are reported (Woodward, 1999).

The advantage of EGEM is that it predicts gully erosion rates and soil loss (one of the few models that can do so) for a single storm event or for average annual conditions (Nachtergaele et al., 1999). The limitations, however, are that it is not capable of predicting ephemeral gully erosion for Mediterranean environments (Nachtergaele et al., 1999). It is unable to predict mean ephemeral gully cross-sections (Nachtergaele et al., 1999). The applicability of EGEM is limited by extensive data requirements, namely the concentrated flow length (Gordon et al., 2006). It is also limited to the processes of incision and widening only, neglecting lengthwise growth of an ephemeral gully system within a single or over multiple runoff events (Gordon et al., 2006). Limitations also involve the use of the diameter and specific gravity of a representative particle to calculate sediment transport capacity (Gordon et al., 2006). There are two significant limitations to this approach: 1) for any material to be detached, the amount of sediment carried by the water must be below transport capacity, thus deposition cannot be simulated, and 2) because soil particle diameter and specific gravity are simplified to some representative or dominant value, the soil material delivered to the mouth of the gully contains the same ratio of clay, silt, sand, and aggregates in the soil in situ (Gordon et al., 2006).

Revised Ephemeral Gully Erosion Model (REGEM)

REGEM was designed to overcome limitations of the current technology (i.e. EGEM) with regard to ephemeral gully erosion (Gordon et al., 2006). It was intended to function as a stand-alone tool, but be able to be incorporated as an individual model within the AnnAGNPS model, giving it the ability to explicitly account for ephemeral gullies in its erosion routines at the sub-cell scale (field scale) (Gordon et al., 2006). Structurally, the model was designed specifically to comply with the computational framework of the AnnAGNPS suite of watershed modeling tools (Gordon et al., 2006). REGEM operates at the sub-cell scale (field scale), where parameters dealing with topography, soil, and management are singular and static for a modeled ephemeral gully (Gordon et al., 2006). Improvements to REGEM include runoff or storm events as unsteady, spatially-varied flows (Gordon et al., 2006). It addresses the upstream migration of a headcut, thereby removing the ephemeral gully length as an input parameter (Gordon et al., 2006). REGEM can determine channel width from discharge, allowing channel dimensions to be explicitly predicted at any point in time and space (Gordon et al., 2006). It can also route five distinct particle class sizes (clay, silt, sand, and small and large aggregates) through gully and the downstream sorting of these sediments (Gordon et al., 2006).

The inputs of REGEM include event peak discharge, event runoff volume, average thalweg slope, Manning's roughness, tillage depth, drainage area to gully mouth, clay ratio in surface soil, silt ratio in surface soil, sand ratio in surface soil, small aggregate ratio in surface soil, large aggregate in surface soil, soil bulk density, critical shear stress of surface soil, headcut erodibility coefficient, integer value classifying current soil conditions (Gordon et al., 2006). The output of REGEM estimates the process of ephemeral gully erosion at the sub-cell scale, and will become part of the continuous simulation of runoff and erosion on agricultural lands (Gordon, 2005).

In terms of predictive accuracy, REGEM allows a more accurate and physically based examination of sediment sources in agricultural watersheds (Gordon et al., 2006). The advantages are that it overcomes several limitations of EGEM, the ephemeral gully length has been removed as an input parameter as gullies now develop along a given length through headcut migration and plunge pool erosion processes (Gordon et al., 2006). The unsteady spatially varied flows allow sediment transport and deposition to be examined explicitly (Gordon et al., 2006). The sediment routing calculations address give particle size classes, accounting for differences between the ephemeral gully sediment flux and the in situ soil material (Gordon et al., 2006). REGEM also integrates with AnnAGNPS, giving AnnAGNPS the ability to explicitly account for ephemeral gully erosion with a minimum of additional input data (Gordon et al., 2006). The disadvantages of REGEM lie in identification of and relationships to quantify: 1) ephemeral gully width, 2) soil resistance to gully erosion, including definition for non-erosive layers, 3) the effect of root mass and above-ground vegetation on erosion resistance, 4) ephemeral gully networks, and 5) the effect of subsurface flow on ephemeral gullies (Bingner et al., 2009).

Agricultural Nonpoint Source Model (AGNPS)

AGNPS was developed by the USDA in response to the need to quantitatively examine the influence of non-point source pollution on surface water and groundwater quality in agricultural watersheds (Sharpley et al., 2002; Merritt et al., 2003; Aksoy and Kavvas, 2005; Wu et al., 2013; USDA, 2015a). It was developed with the intention to help the user create a new or modify an existing annualized pollutant loading model (AnnAGNPS) data set (USDA, 2015a), and is used appropriately to compare the impacts of alternative land management strategies on surface water quality (Young et al., 1989; Panuska et al., 1991). Structurally, AGNPS contains a mix of empirical and physics-based components, and utilizes components of RUSLE for predicting soil loss in grid cells (Merritt et al., 2003). It allows for spatially varied soil and land use input parameters (Wu et al., 2013). AGNPS is free per the USDA (Appendix B).

The input data include parameters describing watershed morphology and land use variables and precipitation data (Merritt et al., 2003). Each grid cell has input parameters which include: cell number (from); receiving cell number (to); Soil Conservation Service curve number; channel indicator, which indicates the existence of a defined channel in a cell; land slope; land slope shape factor; field slope length; channel slope; channel sideslope; Manning's roughness coefficient; soil erodibility factor cover and management factor; support practices factor; surface condition constant; aspect; soil texture; fertilization level; fertilization availability factor; point source indicator; gully source level; Chemical Oxygen Demand factor; and impoundment factor (Merritt et al., 2003).

The outputs for AGNPS has four different output types: 1) watershed level outputs; 2) hydrological outputs; 3) nutrient outputs; and 4) sediment outputs. The watershed level output uses a grid cell representation of the watershed with cell resolution ranging from 0.4 to 16 ha, which makes it possible to analyze spatially discrete management units (fields) within a watershed (Sharpley et al., 2002; Merritt et al., 2003; Aksoy and Kavvas, 2005). It also has outputs for storm precipitation characteristics and the storm energy intensity value (Merritt et al., 2003). The hydrological outputs are water and sediment yields by particle size class and source (USDA, 2015a), runoff volume, peak runoff rate, and the fraction of runoff generated in the runoff rate (Merritt et al., 2003). Nutrient output provides data related to soluble and attached nutrients (N, P, and organic carbon) and any number of pesticides are provided (USDA, 2015a). Nutrient concentrations from feedlots and other point sources, and individual feedlot potential ratings can also be derived within the nutrient outputs (USDA, 2015a). Sediment output provides sediment yield, sediment concentration, sediment particle size and distribution, upland erosion, amount of deposition (%), sediment generated in the cell, enrichment ratios by particle size, and delivery ratios by particle size (Merritt et al., 2003). The pollutant loading model computes sediment bound N, soluble N in runoff, sediment bound P, soluble P in runoff, and sediment bound organic carbon (Merritt et al., 2003).

The predictive accuracy of this model is greatly influenced by the grid size selected by the model user, which in turns influences the sediment yield calculations (Panuska et al., 1991). In 1993, Vieux and Needham found total runoff volume predicted from AGNPS decreases with increasing cell size. Bhuyan et al. (2001) reported a decreasing trend of AGNPS simulated total runoff volume, but an increase peak runoff with increasing cell size. Davenport et al. (2003) found both AGNPS simulated total runoff volume and peak runoff rate increase with increasing cell size. Wu et al. (2013) found that estimated total runoff from the model yields results within 2.5% accuracy using data set at a cell size of 1920 m or smaller, and within 0.2% accuracy using data set at a cell size of 210 m or smaller. Thus care needs to be taken when applying such model to ensure that the resolution chosen for modelling is adequate for the task (Merritt et al., 2003). One major advantage of AGNPS is that it has extensive modeling capabilities (Merritt et al., 2003), however, limitations are that it requires a large amount of data, and has a larger computational complexity compared to other empirical models (Merritt et al., 2003).

Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS)

ANSWERS was developed in the late 1970s by Beasley and Huggins. It was a distributed parameter, event-oriented, planning model developed to evaluate the effects of BMPs on surface runoff and sediment loss from agricultural watersheds (Dillaha et al., 2006). It was intended to simulate and focus on the sediment and erosion components and behaviors (as opposed to AGNPS which placed more emphasis on nutrient components and utilized existing models) of watersheds having agriculture as their primary land use, during and immediately following a rainfall event (Merritt et al., 2003). ANSWERS is a physically based model which uses cellular/grid approach modelling that divides the landscape into cells which are modelled individually and summed for the watersheds (Merritt et al., 2003).

There are four main categories of landform parameters: 1) soil; 2) land uses; 3) elevation based slopes and aspects; and 4) channel descriptions (Fisher et al., 1997; Merritt et al., 2003; Dillaha et al., 2006), however for each major category, other variables are required. Soil type, for example, requires inputs of: total porosity, field capacity, stead state infiltration, the difference between steady state and maximum infiltration, the rate of decrease in infiltration with an increase in soil moisture, infiltration control zone depth, antecedent soil moisture, and erodibility (Merritt et al., 2003; Dillaha et al., 2006). The primary outputs are runoff and erosion (Fisher et al., 1997; Merritt et al., 2003). ANSWERS has been extended to include nutrients, (Moore and Gallant, 1991; Merritt et al., 2003), and the user interface provides a variety of output options such as: storm by storm, annual, average annual values, among others (Dillaha et al., 2006).

In terms of accuracy, the model requires large amounts of data that many watersheds lack, therefore these parameters will need to be calibrated to ensure accuracy (Merritt et al., 2003). The advantages to ANSWERS are that it is both temporally and spatially distributed, providing an advantage over less complex models like USLE (Merritt et al., 2003). Another advantage is the effects of rainfall intensity and spatial variation in soil infiltration capacity, surface conditions, and topography are explicitly represented (Merritt et al., 2003). ANSWERS is limited in applicability by the large spatial and temporal input data requirements (Merritt et al., 2003). From spatial sensitivity analysis on the model, Fisher et al. (1997) determined that many outputs were insensitive to changes in the spatial distribution of input variables to the model, of which they presume it could be due to 1) lack of variability of important parameters in the study catchment, 2) key model components were unaccounted for, or 3) variables not subjected to spatial mixing in any run may swamp the effect of mixing. In addition, ANSWERS considers erodibility to be a relatively time constant parameter, contrary to the large variations in this parameter that have been recorded, this assumption is likely to limit the effectiveness of the model in predicting runoff and soil erosion (Merritt et al., 2003).

Limburg Soil Erosion Model (LISEM)

LISEM was developed by the Department of Physical Geography at Utrecht University and the Soil Physics Division at the Winard Staring Centre in Waneningen, the Netherlands for planning and conservation purposes (Merritt et al., 2003). It is one of the first models to integrate and use GIS (Aksoy and Kavvas, 2005). It was intended to simulate runoff and erosion from individual rainfall events in agricultural watersheds ranging in scale from 0.01 km^2 to approximately 100 km^2 (Merritt et al., 2003). Structurally, it is based on the experiences with ANSWERS, although process descriptions have been highly modified (Merritt et al., 2003). It is based on the solution of a number of physics based equations describing water and sediment yield processes (Merritt et al., 2003). Although physics based, LISEM mostly uses empirically derived equations (Aksoy and Kavvas, 2005). LISEM can be downloaded for free (Appendix B).

Due to the GIS nature, LISEM's inputs are in the form of GIS maps – approximately 25 maps are required for simulation – including maps describing catchment morphology, leaf area index, random roughness of the soil, and the fraction of the soil with crop cover (Merritt et al., 2003). In addition to the maps, rainfall data from multiple rainfall gauges must also be incorporated (Merritt et al., 2003). The outputs are totals for such variables as runoff, sediment, infiltration, and storage depression (Merritt et al., 2003). Maps that show the spatial distribution of such factors as soil erosion and deposition, maps of overland flow at desired time intervals during the simulation, and maps showing the spatial distribution of rainfall intensity (Merritt et al., 2003). LISEM is also capable of producing hydrographs and sediment graphs for rainfall event simulations (Merritt et al., 2003).

The predictive accuracy is dependent upon the input maps, with factors such as resolution, quality, and precision (Merritt et al., 2003). The advantages of LISEM are that it is event based and incorporates both the spatial and temporal variability of rainfall (Merritt et al., 2003). The model is also fully distributed as it is completely incorporated in a GIS with model algorithms applied to each grid cell in a study region

(Merritt et al., 2003). The limitations of LISEM are that it requires detailed spatially and temporally variable data inputs, and often, there are limited datasets for variables other than topography (Merritt et al., 2003). LISEM is constrained by the resolution and quality of GIS inputs (Merritt et al., 2003). It also suffers from difficulties associated with identifiability and data availability as most other physics based models (Merritt et al., 2003).

Environmental Policy Integrated Climate (EPIC)

EPIC was developed in 1981 to determine the relationship between soil erosion and productivity throughout the USA (Williams, 1990). It was developed in time to analyze the relationship between erosion and productivity for the Soil and Water Resources Conservation Act mandated report in 1985 (Sharpley and Williams, 1990). Since its inception, EPIC has been continually improving through additions of algorithms to simulate water quality, climate change and the effect of atmospheric carbon dioxide concentration and N and Carbon (C) cycling (Williams and Steglich, 2009). It was intended as a useful tool for determining optimal management strategies from the farm to the national level (Sharpley and Williams, 1990). It was also intended to predict the effects of management decisions on soil, water, nutrient and pesticide movements and their combined impacts on soil loss, water quality, and crop yields for an area with homogeneous soils and management (Williams and Steglich, 2009). Structurally, the model is a field scale, daily time step model which consists of a) physically based components for simulating erosion, plant growth, and related processes; and b) economic components both for assessing the cost of erosion and for determining optimal management strategies (Sharpley and Williams, 1990). It is a continuous precipitation runoff/water quality model that is designed to simulate drainage areas that are characterized by homogenous weather, soil, landscape, crop rotation, and management (Williams and Steglich, 2009). EPIC is free per Texas A&M University (Appendix B).

The input data can be categorized into four areas, 1) field characteristics data; 2) climate data (daily); 3) soils data; and 4) crop data. For field characteristics data, parameters include: channel lengths, routing lengths, field area, channel and upland slope (Williams and Steglich, 2009). For daily climate data, parameters include: precipitation, minimum temperature, maximum temperature, solar radiation (not required), and wind speed (not required) (Williams and Steglich, 2009). For soils data, parameters include: type, structure, texture, and infiltration characteristics (Williams and Steglich, 2009). Finally, crop data requires growth parameters for each crop, such as: growth temperature, leaf area index, rooting depth, etc. (Williams and Steglich, 2009). Outputs of EPIC are also in four categories: 1) hydrology; 2) weather; 3) soils; and 4) crop data. The hydrology output includes surface runoff volumes and peak runoff rates, lateral subsurface flow, surface flow, percolation, drainage system flow, evapotranspiration, soil and plant evaporation, snowmelt, water table dynamics (height, maximum water depth) (Williams, 1990; Sharpley and Williams, 1990). The weather output provides data on precipitation, air temperature and solar radiation (daily max and min), wind, relative humidity (Williams, 1990; Sharpley and Williams, 1990). Soils output provides data on soil erosion (wind and water – rainfall and runoff), soluble nutrient yield (leaching, transport for N and P), sediment yield, and soil temperature

(Williams, 1990; Sharpley and Williams, 1990). Crop data outputs include potential growth for annual and perennial crops, potential water use, nutrient uptake, water stress, nutrient stress, aeration stress, temperature stress, crop yield, tillage simulating ridge height/surface roughness, drainage, irrigation, fertilization (Williams, 1990; Sharpley and Williams, 1990).

The model user can set the parameters in EPIC or use the parameters supplied with the model for calibration (Williams and Steglich, 2009). The advantages of EPIC are that it functions on daily time step and can simulate hundreds of years (TAMU, 2015b). It is a versatile model with continual added algorithms to improve the model and increase the range of the model (Gassman et al., 2005). EPIC has been used in the assessments of sediment and nutrient loss as a function of different tillage systems, crop rotations, fertilizer rates, nitrate-nitrogen loss via subsurface tile drainage; soil loss due to wind erosion; climate change impacts on crop yield and/or soil erosion; irrigation impacts on crop yield; and estimation of soil temperature and soil C sequestration as a function of cropping and management systems (Gassman et al., 2005; Williams and Steglich, 2009). EPIC is widely accepted around the world as a complete field scale hydrological and crop growth model (Williams and Steglich, 2009). The model is limited by a number of sensitive parameters. The NRCS curve number and curve number index coefficient (if the variable daily soil moisture index used) are influential for runoff and water related output variables such as soil loss by water, N and P losses in runoff (Williams and Steglich, 2009). The RUSLE *C* factor coefficients (parameter 46 and parameter 47) and P factor are influential for erosion, sediment yield, and N and P losses in sediment (Williams and Steglich, 2009). The available soil water capacity (the difference of soil water contents at field capacity and wilting point), potential heating units (the number of heat units expected for a typical growing season – from planting date to harvest date – for the crop to mature), biomass-energy ratio (the crop parameter for converting solar energy into biomass), and harvest index (the ratio of economic yield to the above-ground biomass) are influential for the crop growth components (Williams and Steglich, 2009).

Agricultural Policy/Environmental eXtender (APEX) Model

As an extension of the EPIC model, APEX was developed in the 1990s to address environmental problems associated with livestock and other agricultural production systems on a field scale, whole farm scale, or small watershed scale (Gassman et al., 2005; Kumar et al., 2011). It was developed from several existing and well tested models (Wang et al., 2008; Kumar et al., 2011). APEX was intended to evaluate various land management strategies considering sustainability, erosion (wind, sheet, and channel), economics, water supply and quality, soil quality, plant competition, weather and pests in small watersheds or field (TAMU, 2015a). APEX is based on daily time step (Harman et al., 2004; Kumar et al., 2011) that can perform long term continuous simulations (TAMU, 2015a). The code for APEX is written in Formula Translating System (FORTRAN) and consists of 12 major components: climate, hydrology, crop growth, pesticide fate, nutrient cycling, erosion-sedimentation, C cycling, management practices, soil temperature, plant environment control, economic budgets, and subarea/routing. It also has aspects of feedlot simulations, groundwater and reservoir components (Gassman et al., 2010). It is free per Texas A&M (Appendix B).

Inputs for APEX are extensive, among them are: 1) hydrology; 2) weather; and 3) soils. The input parameters for hydrology are: incoming precipitation; surface runoff volume and rate; subsurface flow; percolation; and potential evaporation (Gassman et al., 2010; TAMU, 2015a). The weather input parameters are: daily precipitation; maximum and minimum temperature; solar radiation; wind speed/direction; and relative humidity (Gassman et al., 2010; Kumar et al., 2011; TAMU, 2015a). The soil input parameters include: soil properties; watershed management grazing schedule; site information; soil texture; soil pH; soil Cation-Exchange Capacity; organic C; soil bulk density; saturated hydraulic conductivity; and soil water content (Gassman et al., 2010; Kumar et al., 2011; TAMU, 2015a). Hydrological outputs of APEX routes water through channels or floodplains to simulate long-term water, sediment, nutrient, and pesticide yield from whole farms and small watersheds (Gassman et al., 2010; TAMU, 2015a). It also determines the amount of flood storage (reservoir component) (Gassman et al., 2010; TAMU, 2015a). The soil output calculates wind induced erosion based on soil properties, surface roughness, vegetation cover, and wind direction (Gassman et al., 2010; TAMU, 2015a). It also calculates water induced erosion in response to rainfall, snowmelt, and irrigation runoff events (Gassman et al., 2010; TAMU, 2015a). The soil output also estimate soil changes as a function of climate conditions, soil properties and management practices (Gassman et al., 2010; TAMU, 2015a). A crop output simulates potential daily growth of annual/perennial crops, trees, and other plants (up to ten plants in a mixed stand) (Gassman et al., 2010; TAMU, 2015a). It also simulates actual growth constrained by stresses (water, temperature, nutrients, and aeration) (Gassman et al., 2010; TAMU, 2015a). A nutrient output estimates soluble P runoff, leaching, mineralization, and immobilization of P and crop intake of P (Gassman et al., 2010; TAMU, 2015a). It also simulates storage and transfer of C and N among pools (Gassman et al., 2010; TAMU, 2015a). It also simulated the complete N-cycle: atmospheric N inputs, fertilizer/manure N applications, crop N uptake, mineralization, immobilization, nitrification, denitrification, ammonia volatilization, organic N transport on sediment, and nitrate-nitrogen losses in leaching, surface runoff, lateral subsurface flow, and tile flow (Gassman et al., 2010; TAMU, 2015a).

The default values of the parameters provided in the model were sufficient for accuracy, but Kumar et al. (2011) adjusted the parameters to determine the sensitive parameters for more precise results. The advantages of APEX is that it is well suited to evaluate long-term effects of conservation practices on cropland due to its strength in simulating agricultural management systems (Wang et al., 2006). It also extends EPIC's capabilities to whole farms, multiple fields, and small watersheds to examine implications of farm management within context of the natural landscape and cropping patters (Williams, 1990; Sharpley and Williams, 1990). There are also a wide variety of interfaces to run APEX, such as: Interactive APEX; WinAPEX; WinAPEX-GIS; SWAT-APEX; and ArcGIS APEX (Gassman et al., 2010). APEX is sensitive to the following parameters for runoff: Curve Number (CN) retention parameter, and CN parameters: runoff CN initial abstraction and Hargreaves Potential Evapotranspiration (PET) equation coefficient (Kumar et al., 2011). It is also sensitive to the following parameters for sediment yield: sediment routing exponent, sediment routing coefficient, and sediment routing travel time coefficient (Kumar et al., 2011).

Chemical Runoff and Erosion from Agricultural Management Systems (CREAMS)

The CREAMS model was the first to separate rill and interrill erosion processes (Wang et al., 2013). CREAMS's algorithms have been used in numerous models including WEPP (Merritt et al., 2003). It was developed as a tool to evaluate the relative effects of agricultural practices on pollutants in surface runoff and in soil water below the root zone (Knisel, 1980; Lane et al., 1992; Lane et al., 1995; Merritt et al., 2003). CREAMS was intended to be physically based, and not need calibration for each specific calibration, but it ended up retaining empirical aspects in the model's algorithms (runoff component and aspects of the erosion module) (Merritt et al., 2003). The model structure consists of three components: hydrology; erosion/sedimentation; and chemistry and target non-point source pollutants (Merritt et al., 2003). The process of sediment transport and deposition are described using physics based sediment transport capacity relationships (Merritt et al., 2003). It can operate either on a continuous or event basis, and is designed for application in field sized areas (approximately 40 hectares up to 400 hectares) that are uniform in soil, topography, and land use (Merritt et al., 2003).

The inputs for CREAMS are precipitation series, monthly air temperature and solar radiation values and soil and crop type data (Merritt et al., 2003). The output predicts erosion, deposition and transport of sediment on a slope profile and into first and second order channels (Silburn and Lock, 1991; Merritt et al., 2003). In terms of hydrology, the model calculates flow volume, peak flow, soil infiltration, evapotranspiration, soil water content, percolation to groundwater, and sediment yield on a daily or even basis (Merritt et al., 2003). Outputs from CREAMS are provided for field size catchment assumed uniform soil topography and land use (Merritt et al., 2003).

The dynamic nature of runoff erosion may limit the prediction accuracy that can be obtained using a physics based model rather than a statistical model, as the accuracy of the CREAMS model will be highly dependent on the accuracy of the input data (Govers and Loch, 1993; Merritt et al., 2003). The advantages of CREAMS is that it accounts for gully erosion and deposition, in addition to overland erosion sources (Merritt et al., 2003). It can predict ephemeral gully erosion rates, which can produce as much or more sediment than sheet or rill erosion (Lane et al., 1992; Merritt et al., 2003). It analyzes the rill and interrill areas separately (Aksoy and Kavvas, 2005, Wang et al., 2013). The model also allows for the erodibility factor to be updated from one runoff event to the next due to high variability of the factor (Govers and Loch, 1993; Merritt et al., 2003). The limitations of CREAMS is that it has an unrealistic assumption of the plot or catchment area being modelled is assumed to be uniform in soil topography and land use (Merritt et al., 2003). The applicability is limited by extensive data requirements, namely the concentrated flow length (Gordon et al., 2006). CREAMS is limited to the processes of incision and widening only, neglecting lengthwise growth of an ephemeral gully system within single or over multiple runoff events (Gordon et al., 2006). It is limited by the use of the diameter and specific gravity of a representative particle to calculate sediment transport capacity (Gordon et al., 2006). Similar to EGEM, there are two significant limitations to this approach: 1) for any material to be detached, the amount of sediment carried by the water must be below transport capacity, thus deposition cannot be simulated, and 2) because soil particle diameter and specific gravity are simplified to some representative or dominant value, the soil material delivered to the mouth of the gully contains the same ratio of clay, silt, sand, and aggregates in the soil in situ (Gordon et al., 2006).

Hydrologic Simulation Program, Fortran (HSPF)

HSPF was developed in the 1960s for the simulation of watershed hydrology and water quality (N, P, suspended sediment, and other toxic organic or inorganic pollutants) at a catchment scale (Walton and Hunter, 1996; Merritt et al., 2003). It was intended to be a generic model designed to apply to most catchments using existing meteorological and hydrological data, soils and topographic information, and information on drainage and other characteristics (Rahman and Salbe, 1993; Merritt et al., 2003). The model structure consists of three main modules: the pervious land module, the impervious land module, and the river/mixed reservoir module (Merritt et al., 2003). HSPF considers in detail most of the processes in moving sediment and nutrients through a catchment by conceptualizing these processes and requires calibration against measured water quantity and quality constituents, thus distinguishing it from physics-based models (Merritt et al., 2003). HSPF can be downloaded for free (Appendix B).

The inputs for HSPF include: rainfall; evaporation; air and water temperature; solar radiation; sediment grain size distribution; point source discharge volume; and water quality data (Cheung and Fisher, 1995). The outputs include the simulation of a wide range of water quality components such as: temporal history of runoff; flow rate; sediment load and nutrient components; and a time series of water quantity and quality at any sub catchment outlet in the catchment (Merritt et al., 2003). HSPF simulates the meteorological and land-based processes important to the understanding the sources of nonpoint source loadings required in TMDLs (Whittemore and Beebe, 2000).

In terms of predictive accuracy, the streamflow and instream water quality is used to validate the model results (Merritt et al., 2003). The advantages of HSPF are that the model is catchment scale, conceptual model where the catchment is divided into hydrological homogenous land segments, and water quality and quantity is calculated for each land use in each segment (Merritt et al., 2003). It is one of few conceptual models of watershed hydrology and water quality that explicitly integrates the simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions (Merritt et al., 2003). It is limited in that it is difficult to understand and effectively use (Whittemore and Beebe, 2000). It also relies heavily on calibration against field data for parameterization; with the relatively large number of parameters required, this raises problems associated with parameter identifiability and the physical meaningfulness of model parameters (Walton and Hunter, 1996; Whittemore and Beebe, 2000; Merritt et al., 2003). HSPF is a nondistributed model (lumped parameters) and is therefore unable to handle the variety of site variables important for multiple land use management effects at a meaningful field scale (Whittemore and Beebe, 2000).

Water Erosion Prediction Project (WEPP)

WEPP is a physics based model developed around the mid-1980s in the USA in an initiative between the Agricultural Research Service, the Soil Conservation Service, the Forest Service in the Department of Agriculture and the Bureau of Land Management in the Department of Interior (Laflen et al., 1991; Merritt et al., 2003; Charlton, 2008; Wang et al., 2013). It was intended to determine and/or assess the essential mechanisms controlling erosion by water, including anthropogenic impacts in agricultural areas, but has since evolved to include forest areas (Merritt et al., 2003; Fu et al., 2010). The model is spatially distributed and operates on a daily – continuous time-step that produces annual-average and multiple sized outputs (Merritt et al., 2003; Fu et al., 2010; Wang et al., 2013). WEPP uses mainly physics-based equations to describe hydrologic and sediment generation and transport processes at the hillslope and in-stream scales (Merritt et al., 2003). It is based on the concept that erosion takes place by two different but complementary sub-processes: interrill and rill erosion (Wang et al., 2013). WEPP can be downloaded for free (Appendix B).

The inputs can be divided into four categories: 1) crop; 2) hydraulic; 3) soil; and 4) watershed. The crop input include: canopy cover and height, above and below ground biomass of living and dead plant material, leaf area index, and basal area, and are estimated on a daily basis (Laflen et al., 1991). Date and management practices are essential inputs to the model; and plant characteristics are of utmost importance to describe adequately as they have a large impact on the soil erosion and hydrological processes in the site (Merritt et al., 2003). The hydraulic inputs include: surface runoff volumes, hydraulic roughness, and approximations of runoff duration and peak rate

(Merritt et al., 2003). The soil inputs include: effect of management practices, weathering, consolidation, and rainfall on soil and surface variables (random roughness, bulk density, saturated hydraulic conductivity, and the erodibility factors of the rill and interill) (Laflen et al., 1991). Lastly, the watershed inputs include channel topography, channel soils, channel management, and the channel hydraulic characteristics (Merritt et al., 2003). The output of WEPP gives estimates of the spatial and temporal distribution of soil loss, sediment yield, sediment size characteristics, runoff volumes, and the soil water balance at hillslope or small catchment scales (Flanagan and Nearing, 1995; Merritt et al., 2003). WEPP considers sediment deposition and is applicable from the top of a hillslope to a channel (Merritt et al., 2003). The basic output contains the runoff and erosion summary on a storm-by-storm, monthly, annual, and average annual basis (Merritt et al., 2003).

With a large amount of computational and data requirements, WEPP will need to be calibrated, and watersheds lacking data will need parameter calibration (Merritt et al., 2003). The advantages of WEPP is that it can predict spatial and temporal distribution of soil detachment and deposition on an event or continuous basis at both small (hillslopes, roads, small parcels) and large (watershed) scales (Merritt et al., 2003). It provides an estimation of sheet and rill erosion, deposition, and sediment delivery from hillslopes (Merritt et al., 2003). It also provides an estimation of erosion and deposition in channels such as ephemeral gullies and grassed waterways (Merritt et al., 2003). It can determine the impacts of impoundments (Merritt et al., 2003). It can predict runoff and sediment delivery from small watersheds (Merritt et al., 2003). It also performs well over a wide range of soils and soil conditions (Wang et al., 2013). WEPP is limited in that it requires large computational and data requirements, which limits its applicability, specifically for concentrated flow length (Merritt et al., 2003; Gordon et al., 2006). It does not consider erosion, transport and deposition processes in permanent channels, such as classical gullies and perennial streams, which in some river catchments can be the largest contributor to sediment load (Merritt et al., 2003). It is not applied to large watersheds with perennial stream (Merritt et al., 2003). The rill-interill concept of erosion used by WEPP may not be applicable in soils that have been cultivated and do not initially exhibit rill formations, thus the need to expand coverage for croplands and rangeland plants (Merritt et al., 2003; Wang et al., 2013). It is limited to the processes of incision and widening only, neglecting lengthwise growth of an ephemeral gully system within single or over multiple runoff events (Gordon et al., 2006). Limitations also involve the use of the diameter and specific gravity of a representative particle to calculate sediment transport capacity (Gordon et al., 2006). Similar to EGEM and CREAMS, there are two significant limitations to this approach: 1) for any material to be detached, the amount of sediment carried by the water must be below transport capacity, thus deposition cannot be simulated, and 2) because soil particle diameter and specific gravity are simplified to some representative or dominant value, the soil material delivered to the mouth of the gully contains the same ratio of clay, silt, sand, and aggregates in the soil in situ (Gordon et al., 2006).

Sediment River Network (SedNet)

SedNet is a steady-state model specifically developed for application at continental scale for the Australian National Land and Water Resources Audit (Merritt et al., 2003). It was intended to estimate sediment generation and deposition from hillslopes, gullies and rivers banks in a river network (Prosser et al., 2001; Merritt et al., 2003). It was to be a tool for addressing land and water management issues at the catchment or larger scale (Merritt et al., 2003). Structurally, SedNet uses simple conceptual and empirical models of sediment detachment, transport, and deposition to describe long-term sediment loads in individual reaches (Merritt et al., 2003).

The inputs for SedNet requires a DEM to define the network of river links to which the model is applied and to calculate topographic attributes for the catchment and each river link (Merritt et al., 2003). The hillslope model requires a grid of mean annual rainfall, soil erodibility, crop management factors, slope length and slope, and management practices (Merritt et al., 2003). The gully erosion model requires a grid of gully density and a description of the mean characteristics for each link (Merritt et al., 2003). SedNet requires descriptions on the in situ sediment, bank vegetation and bank dimensions for modelling in-stream sediment generation and sediment transport (Merritt et al., 2003). SedNet is linked with GIS, therefore it provides outputs of the spatial patterns of sediment entrainment, instream sediment loads and deposition (Merritt et al., 2003).

SedNet requires a large amount of data for each river link, currently the parameter values tend to be prescribed from literature based on empirical or theoretical prior knowledge, thus raises uncertainty in the range of parameter values in the catchment and limiting confidence on the outputs (Merritt et al., 2003). The advantages of SedNet is that as a whole, the model is complex in terms of the large number of river links in the catchment, but it comprises of relatively simple relationship (Merritt et al., 2003). Compared to other grid based models (such as AGNPS), the simplified process representation provides a more manageable tool for initial exploration of the amount and patterns of sediment moving through a catchment (Merritt et al., 2003). SedNet incorporates most of the sediment processes occurring at the catchment scale (Merritt et al., 2003). It attempts to provide a spatial representation of the sources and sinks of sediment in large catchments or basins (Merritt et al., 2003). SedNet has the potential for being a highly useful tool in exploring impacts of land management and stream channel management on downstream sediment transport and deposition processes (Merritt et al., 2003). The limitations of SedNet is that it requires large amount of data for each river link and the cumulative parameter requirements (Merritt et al., 2003). It incorporates most of the sediment processes at the catchment scale, but lumps them together temporally (Merritt et al., 2003). Lastly, the sensitivity of model outputs to the uncertainty of inputs, parameters and the model structure needs to be addressed for more precise outputs (Newham et al., 2001; Merritt et al., 2003).

Model Summary

The models reviewed comprised of a mix of empirical and physics-based components. The models reviewed characterizes many of the approaches that have been used to describe the hydrology and sediment generation, transport, and deposition through landscapes heavily influenced by agriculture (Table 5). The models range significantly in the processes they characterize, the style in which these processes are represented, and the spatial and temporal scales of application for which they were developed.

Due to the large number of models available, the question of which model, when, and where arises. It is apparent that an apropos model selection is dependent on the needs of the user, and the erosion and sediment movement question the user is attempting to address. This will identify the processes that require explicit representation in the model, as well as the spatial and temporal resolution a specific model needs to apply. Then, determining the appropriate model for application requires consideration of the suitability of the model to local catchments conditions and constraints, data requirements, model complexity, the accuracy and validity of the model, model assumptions, spatial and temporal variations, processes of the model, and the objectives of the model user.

Table 5. Processes represented in the hydrologic and sediment transport models reviewed.

Model	Empirical	Physical	Rainfall Runoff	Land Surface Sediment			Gully	Instream Sediment			Sediment Associated Water Quality	
				G	T	D		G	T	D	Land	Instream
USLE	X			X	X	X		X	X	X		
MUSLE	X		X	X	X	X		X	X	X		
RUSLE1	X		X	X	X	X		X	X	X		
RUSLE2	X		X	X	X	X		X	X	X		
BASINS		X			X							X
SWAT		X	X		X	X				X	X	X
EGEM		X	X	X	X	X	X				X	
REGEM		X	X	X	X		X		X	X		
AGNPS		X	X	X			X	X	X	X	X	X
ANSWERS		X	X	X	X	X						
LISEM		X	X	X				X	X	X		
EPIC		X	X		X							
APEX		X	X	X	X				X			
CREAMS		X	X	X	X	X	X				X	
HSPF		X	X	X	X	X	X	X	X	X	X	X
WEPP		X	X	X	X							
SEDNET	X		X	X			X	X	X	X	X	X

G, sediment generation; T, sediment transport; D, deposition

Objective 3: Analyze costs and benefits of evaluated stabilization projects and review of potential stabilization techniques to employ in the management of natural resources.

Analysis of the stabilization projects include three alternatives: 1) no action alternative; 2) a small scale stabilization project of ravines and bluffs; and 3) a large scale stabilization projects of critical and highly erosive ravines and bluffs. Aside from the no action alternative, the other project alternatives include four stabilization approaches: 1) hard armoring; 2) soft armoring; 3) bioengineering methods; and 4) land use practices.

Hard armoring is the use of physical barriers and structures, with techniques including rock riprap (large stones placed along of a streambank or shoreline) and gabions (rock-filled wire baskets placed along a streambank or shore-line) (Prunuske et al., 1987; Dennis, 2001; Koepke, 2010; Shabica et al., 2010). Hard armoring typically involves grading the bank to a gentler slope to address shear stress, velocity, and lateral bank migration (Koepke, 2010). If done properly, these techniques provide very good protection and will work in severe situations where bioengineering will not (Shabica et al., 2010). However, not only can hard armoring techniques be expensive, these techniques fix a stream channel in place and does not allow the stream to adapt to future changes (Prunuske et al., 1987). Hard armoring also has the potential to exacerbate downstream erosion and flooding, and reduces the habitat value for fish and other aquatic and riparian wildlife (Prunuske et al., 1987; Dennis, 2001).

Soft armoring is purely the biological approach, using natural protection methods such as live plants, logs, root wads, vegetative mats, and other methods that eliminate or reduce the need for hard armoring (Prunuske et al., 1987; Koepke, 2010; Shabica et al., 2010). Soft armor is alive and so can adapt to changes in its environment as well as reproduce and multiply (Prunuske et al., 1987). It also provides habitat for fish and wildlife. Vegetative practices, however, must take into account appropriate soil conditions, hydrology, species selection, sunlight regime, management activities, hydroperiod return rates, and other associated factors in order to successfully improve stream erosion using vegetation alone (Koepke, 2010). A list of vascular plants found in Blue Earth County can be found in Appendix C.

Bioengineering methods incorporate structural repairs with vegetation (hard and soft armoring techniques) (Prunuske et al., 1987; Eubanks and Meadows, 2002; Raven et al., 2008; Pennington and Cech, 2010). When they work well, they blend into the riparian habitat within a few years (Pennington and Cech, 2010). They use materials that are either biodegradable or are natural to the stream, such as native plants, logs, and rocks (Prunuske et al., 1987; Shabica et al., 2010). They add wildlife habitat value by increasing cover and shade in the stream channel, and providing food and shelter for animals that use the stream corridor (Prunuske et al., 1987; Pennington and Cech, 2010).

In addition to stabilization approaches, land use practices are the primary and direct measures to control sediment sources (Waters, 1995; Czapar et al., 2006; Raven et al., 2008). Practices to control sheet and rill erosion modify one or more of the factors affecting erosion processes: slope length, slope steepness, cropping and management practices and support practices that slow runoff water or cause deposition

(Czapar et al., 2006). Farmers who employed certain agricultural practices can minimize erosion, and thereby protect their crop. In contrast, rainfall erosivity and soil erodibility, dominant factors affecting soil erosion, cannot be easily modified (Czapar et al., 2006).

Current management practices in the BERB and LSRB have data gaps. There have been 35 applied restoration efforts using BMPS for water erosion control in the BERB (Figure 16) (MNBWSR, 2015). Practice implemented included the use of filter strips, grade stabilization structures, grassed waterways and swales, gravel inlets, streambank and shoreline protection, terracing, and water and sediment control basins. (MNBWSR, 2015), and 161 applied restoration efforts for water erosion control in the LSRB (Figure 17). A simple GIS overlay analysis displayed that no implemented practices overlapped in the BERB, and there were 3 bluff sites in the LSRB that had shoreline and bank protection. These sites, however, were implemented in 2013, after the last LiDar set was acquired in 2012, thus there are no current data to determine if the practices in place are effective. Therefore, the methods for understanding proper and effective use of stabilization techniques will primarily be from case studies from the Midwest region.

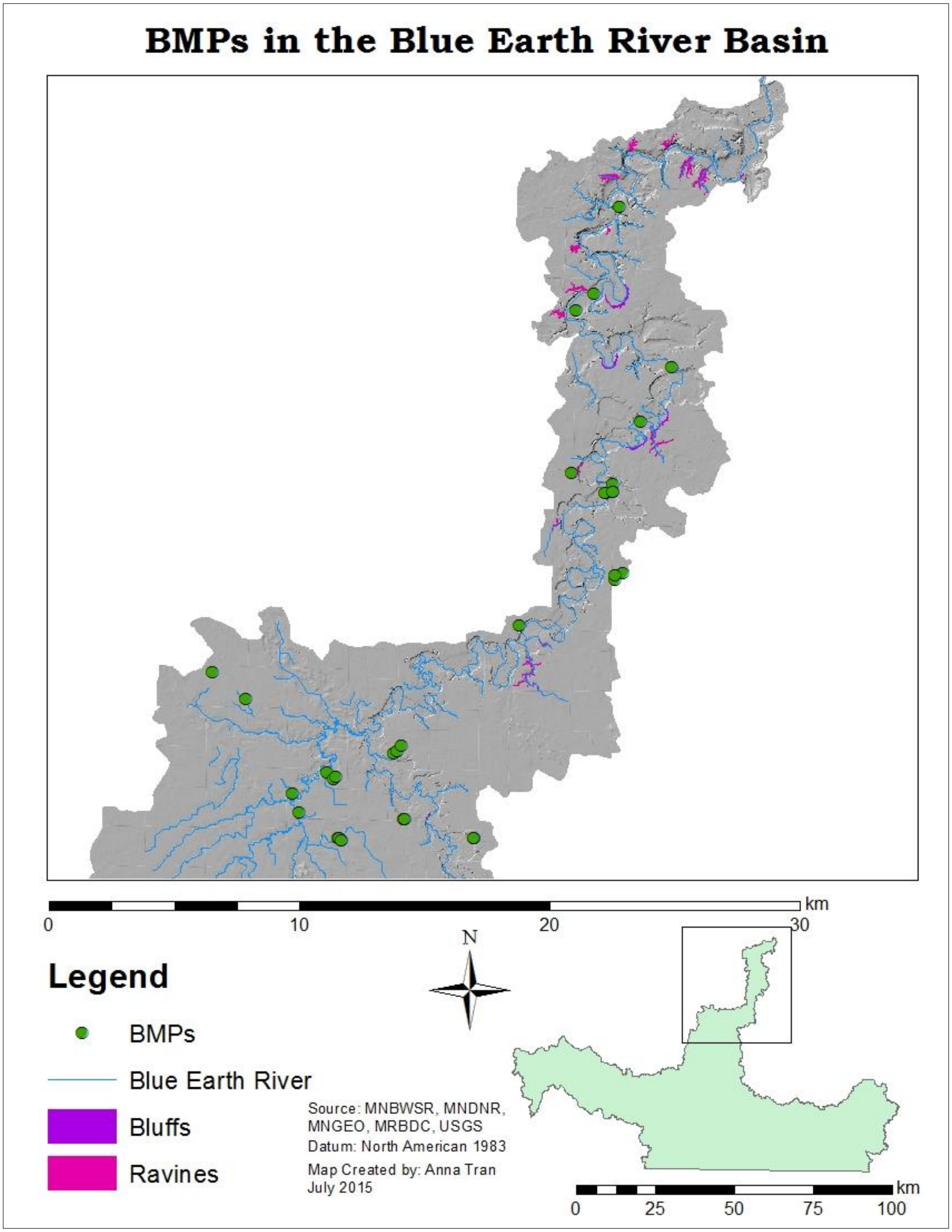

Figure 18. Applied best management practices in the Blue Earth River Basin since 2013. There have been 35 water erosion related practices applied, however, for Blue Earth River, there were no practices applied near the final ravine or bluff sites.

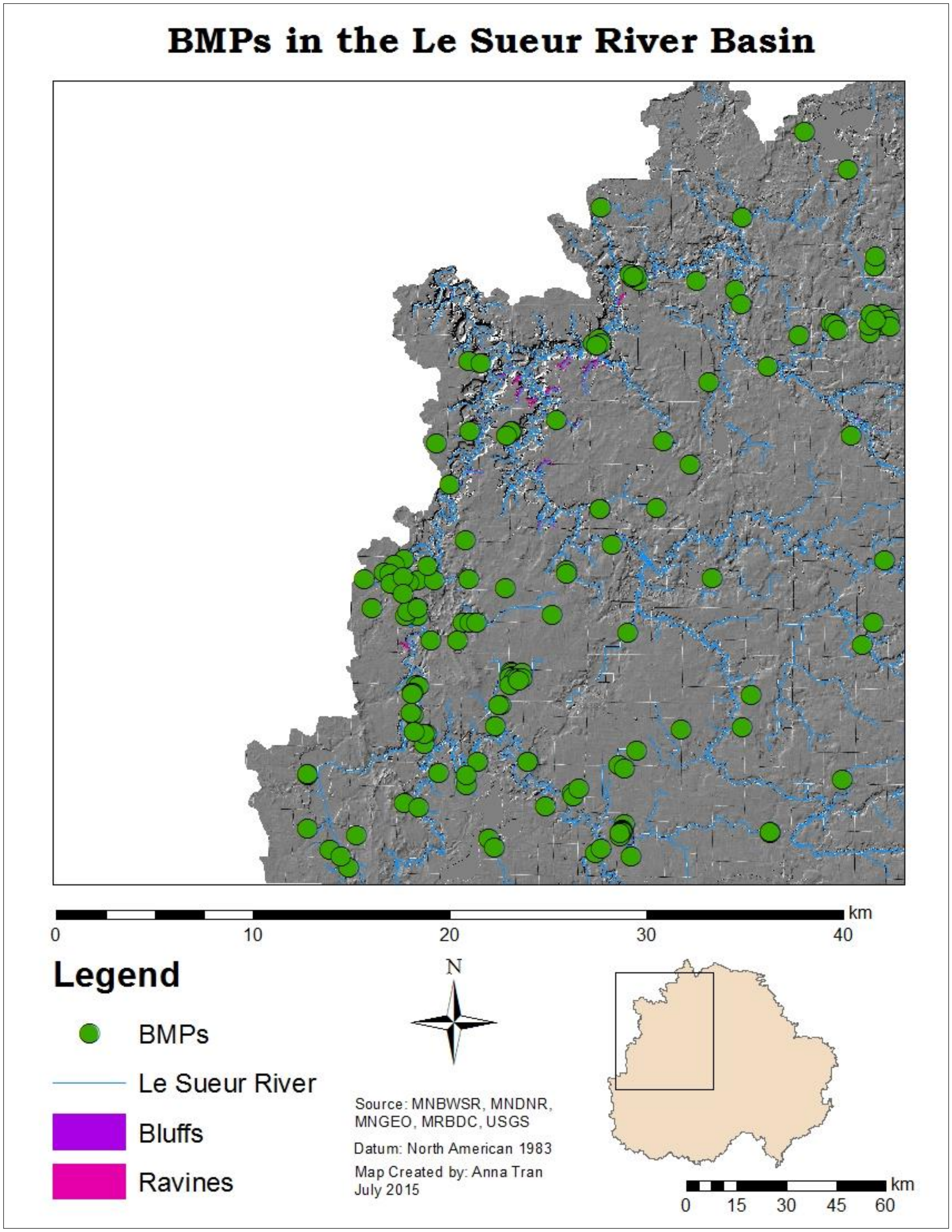

Figure 19. Applied best management practices in the Le Sueur River Basin since 2013. There have been 161 water erosion related practices applied, however, for the Le Sueur River, three water erosion control practices were applied to adjacent bluff sites. However, due to the practices being applied in 2013, and the last LiDar set was acquired in 2012, there is no certainty whether the applied practices have been successful.

Case Studies

Ravine 10, Lake Michigan (Illinois)

Approximately 50 years, ago, interceptor sanitary sewers were installed in the streambeds of several Highland Park ravines, including Ravine 10. The central branch of Ravine 10 flows northeast into Lake Michigan, is approximately 914 m long, and is fed by a sewer drainage at the head of the ravine (Shabica et al., 2010). Active streambed erosion, streambank erosion, soil slump and creep, and damaged sanitary sewer connections were observed in many locations along the axis of this ravine in 1992 (Shabica et al., 2010). In Ravine 10, a variety of erosion control structures were installed before 1992 by adjacent property owners with varying degrees of success; the most common practice employed were retaining walls made of timber ties placed on the upper slopes of the ravine.

Shabica (2010) and his team opted to use hard armoring to stabilize the gradient of the ravine. They utilized gabion baskets made from galvanized steel mesh (similar to chain-link fencing); in 2007, the gabion baskets appeared to be in good condition and effective in retarding ravine slope erosion, however subsided from their original placement, and also appeared to have confined the flow in the ravine, thus increasing its velocity and erosive power (Shabica et al., 2010). Reno mattresses (galvanized steel wire mesh baskets filled with dolomite) were used as well, and in 2007 were still in place and reduced downcutting (Shabica et al., 2010). However, they were not installed far enough upslope to prevent lateral bank erosion both up and downstream. A-Jacks are cast concrete shaped like a child’s six-arm toy jack. The A-Jacks were installed at the toe of the ravine slope on either or both sides of the streambed, or adjacent to and downstream from a Reno Mattress (Shabica et al., 2010), willow cuttings were planted between the A-Jacks directly into existing soil or clay. By 2007, A-Jacks were no longer a significant factor in prevent erosion and had completely failed, consequently, none of the willow trees could be found alive to hold the soil together (Shabica et al., 2010). Geowebs (a plastic textile that is honeycombed) were used in areas of actively eroding clay in the streambed (Shabica et al., 2010). In 2007, they showed minor signs of deterioration, but were intact.

Overall, the A-Jacks failed completely, but the gabions, Reno Mattresses, and Geoweb installations were intact after 15 years. While it seems as though some protection is better than none, a full ravine plan would assure long term stability and erosion control. Ravine 10 illustrates the need for a comprehensive approach in ravine restoration (Shabica et al., 2010), to take into account the morphology of the stream and to mimic the natural stream dynamics.

Kendall County, Illinois

The majority of streams in northeast Illinois that exhibit accelerated streambank erosion are due to either channelization from agricultural practices or channelization and incision due to urbanization and development (Koepke, 2010). A ravine restoration effort in Kendall County, Illinois exhibits some of the successes and potential failures when specifying and installing stone toe protection and grade stabilization structures. The ravine is situated on the top of the historic floodplain of the Fox River (Koepke, 2010). The total ravine stream reach is approximately 365 m in length, with a 19 m elevation change and bed slopes ranging from 10-48% in gradient (Koepke, 2010). The necessary restoration of this channel was due to the installation of a new storm sewer outlet at the head of the ravine, which drained a newly developed residential area, some surrounding roadways, and agricultural areas (Koepke, 2010). The ravine exhibited steep incision within the first year of the drainage outlet, and initial efforts were taken to stabilize the channel bottom through the use of hard armor (small cobble stone, erosion blanket) but failed due to not taking account the volume and velocity of the water entering the ravine (Koepke, 2010). In order to adequately stabilize the ravine, a series of large rock step pools were planned along with additional stone toe protection between grade stabilization structure (Koepke, 2010). The stone selected was carefully considered, in terms of size (78-92 cm) and geometry and parent material (limestone which provided greater structural stability) (Koepke, 2010). In addition to hard armoring, the Koepke, and his team (2010) opted to seed the banks above the stone toe protection with a shade tolerant native seed mix.

The completed restoration work was evaluated for its structural stability and vegetative establishment along the eroded banks and steep slope. Throughout the first year, the vegetation successfully established along the treated reaches of the ravine (Koepke, 2010). The area experienced several high flow events and was put through two severe flood events from a combined snowmelt and rainfall event, and the stabilization structures remained in place and functional (Koepke, 2010). By the second vegetative monitoring in the spring of 2009, the quality and density of the native vegetation along the ravines significantly improved, and the channel down cutting was abated (Koepke, 2010).

Elm Creek (Minnesota)

Elm Creek is a tributary of the BERB within the MRB (Quade, 2000; Lenhart et al., 2011a). The watershed is mostly flat with some steeper slopes in the highly erodible stream valleys (Lenhart et al., 2009). Approximately 700 km^2, wetlands cover less than 2% of the watershed, although historically, it was greater than 50% wetland coverage (Quade, 2000). Drainage of wetlands and lakes has led to increased runoff and sediment delivery to streams (Miller, 1999), including Lake Pepin.

The purpose of the project was to demonstrate cost-effective stream restoration techniques within an economically productive agroecosystem to enhance channel stability, reduce sediment loads, and improve aquatic and riparian habitats (GBERBA, 2010; Lenhart et al., 2010; 2011a). To increase floodplain connectivity, an oxbow cutoff was reconnected (at high flows only) using a cross vane constructed with locally available rock. Cottonwood logs were used as a cost-saving measure (Lenhart et al., 2010; 2011a). To reduce the highest rates of bank erosion, revetment logs were placed along the outer bend into the direction of flow and secured to the bank with duckbill anchors to divert flow away from the bank (Lenhart et al., 2010; 2011a). An actively flooded bankfull “bench” was constructed within the incised portion of the channel (Lenhart et al., 2010; 2011a). Following hard armoring with grading and in-stream work, a native prairie seed mix was obtained from a local supplier, and was hand spread on the streambanks and covered with a straw coconut erosion control fabric (Lenhart et al., 2010; 2011a). Willow cuttings were collected from a nearby stand and planted along 600 m of streambanks to increase channel roughness, and enhance stability through root strength (Lenhart et al., 2010; 2011a). Finally, a rotational grazing plan was proposed to initially fence cattle out of the restoration area and gradually rotate them back into the riparian zone at low densities and short durations to avoid soil compaction and overgrazing (Lenhart et al., 2010; 2011a).

In the first year following restoration (2009), the stream stabilization project withstood overbank flow during spring snowmelt (Lenhart et al., 2010). From 2010-2011, a riparian corridor management study was implemented, which included post-restoration monitoring (Lenhart et al., 2011a). Preliminary findings suggest that reductions in bank erosion have occurred where logs were placed to divert flow from the outer bend (Lenhart et al., 2010; 2011a). This area exhibited reduced peak flows and sediment load from the contributing watersheds (Lenhart et al., 2011a). Total Suspended Sediment (TSS) removal exceeded 90%, and was effective at reducing TSS, turbidity, and N (Lenhart et al., 2011a).

From these case studies, we learn the appropriate and effective approach. Soft armoring and bioengineering approaches were most effective, and are recommended techniques to implement in managing an eroding site. When considering a large scale restoration project, every factor must be taken into account. With ravines, the key variables are slope grade and flow velocity; for bluffs, the key features are toe and downcutting protection. Any lack of consideration can turn a project into a failed attempted very quickly. The next section illustrates three proposed project alternatives that can potentially be implemented as well as their environmental and economic impacts.

No Action Alternative

The no action alternative assumes that no stabilization projects would be initiated within the BERB or LSRB, and no collaborative repair program would be put in place. Instead, erosion repairs would continue to be identified, permitted individually by the applicable regulatory agencies, and implemented when permits were obtained. The stabilization efforts will be conducted on a project by project basis.

Impacts

The environmental benefits of the no action alternative is the creation of soil, new habitat formation, and the binding of Carbon. Soil formation originates from some form of rock, which takes eons to weather away from a solid mass into smaller particles (Raven et al., 2008; Lal, 2010). Sand and clay particles compose the basic soil structure, with varying amounts of silt and organic matter combined to create different textures and nutritional characteristics. Weathering of a rock is a processed called denuding; as a rock crumbles, more components are released into the environment and potentially made available for use by microorganisms and plants (Charlton, 2008; Raven et al., 2008). As rock or soil erodes from one location and moved to a new location, new habitats form for the establishment of life (Waters, 1995). Erosion of soil from a watershed into the river is later deposited downstream on the banks or at the mouth of the river in shallow areas or dunes (Waters, 1995). These newly deposited soil creates new landmass for various life forms to live and prosper (Waters, 1995). Erosion and sedimentation benefit the environment through carbon binding from both the atmosphere and the ground (University of Exeter, 2007). As the sediment rolls over organic matter or is exposed to air, the pores trap or absorb carbon, removing it from the habitat, referred to as carbon sinking (University of Exeter, 2007). Therefore, erosion helps diminish a small amount of buildup of carbon dioxide in the atmosphere.

The environmental disadvantages of erosion are extensive. Erosion promotes the critical loss of water, nutrients, soil organic matter and soil biota, harming forests, rangelands, and natural ecosystems (Pimentel et al., 1995; Ritter and Eng, 2012). The removal of soil may affect soil and plant composition, reducing the soil's ability to store water and retain nutrients to support plant growth (Pimentel et al., 1995; Mamo and Hain, 2005; Pimentel, 2006; Lal, 2010; Ritter and Eng, 2012), thereby reducing its ability to support soil biodiversity (Pimentel et al., 1995; Pimentel, 2006). Higher rates of runoff also increase siltation of waterways, which deposit where there is a reduction of slope in the land, acting as sediment traps along contour banks, in grass waterways, dams or wetlands (Lal, 2010; Ritter and Eng, 2012). Siltation in waterways leads to increased areas prone to flooding (Pimentel et al., 1995; Lal, 2010). Erosion also contributes to the contamination of waterways from fertilizers and pesticides that originate from adjacent agricultural land uses (Pimentel et al., 1995; Lal, 2010; Ritter and Eng, 2012). Toxins from chemical fertilizers and pesticides bind to soils, and once washed into the waterway, increase nutrient pollution which promote algae growth, known as eutrophication (Pimentel et al., 1995; Mamo and Hain, 2005; Pimentel, 2006; Lal, 2010). Once the algae die off and decompose, they reduce and deplete the concentration of dissolved oxygen available, causing the death of other organisms such as fish (Pimentel et al., 1995; Mamo and Hain, 2005; Lal, 2010). Sediments that enter the waterway increases turbidity, which also reduces light penetration and photosynthesis (Pimentel et al., 1995; Mamo and Hain, 2005). The lack of photosynthesis leads to a reduction in dissolved oxygen, which in turn affects the aquatic life (Pimentel et al., 1995; Mamo and Hain, 2005).

Based on extensive literature review and research, there are no economic advantages of erosion. There are, however, many economic disadvantages to erosion, and apply to the no action alternative. The economic impact of soil erosion is significant, Uri (2000) estimates that soil erosion in the US costs the nation about $37.6 billion each year in loss of productivity (Pimentel, 2006). In terms of agricultural production, if no action is taken, erosion will reduce the top soil in arable lands, resulting in lower yields, and higher production costs (Pimentel et al., 1995; Lal, 2010; Ritter and Eng, 2012). Once the top soil has eroded away, erosion causes rills and gullies that make the cultivation of arable lands impossible. Erosion also exposes the subsoil, which has poor physical and chemical characteristics (Pimentel et al., 1995; Ritter and Eng, 2012). Due to the loss of top soil, arable lands become unproductive, and the soil has reduced abilities to store water and nutrients (Pimentel et al., 1995; Ritter and Eng, 2012). The higher rates of runoff sheds valuable nutrients that would otherwise be used for crop growth (Pimentel et al., 1995; Ritter and Eng, 2012). Soil erosion also drastically increases water treatment costs (Lal, 2010). In addition to eutrophication of surface waters, there are also severe problems with contamination of ground water by nitrates and other contaminates (Lal, 2010). Erosion also has economic damage to infrastructure. Siltation is a major problem in reservoirs because it reduces water storage and electricity production and shortens the lifespan and increases the maintenance costs of dams (Pimentel et al., 1995; Lal, 2010). Direct damages from erosion include undermining and damage of private and public structures such as homes and bridges, sediment accumulation on down-slope properties, increased costs needed to clean out, dredge, and maintain drainage channels, and washing out and constant repairs of lanes, roads, and fence rows (Pimentel et al., 1995; Ritter and Eng, 2012).

No Action Alternative Summary

Under the no action alternative, a reactive management approach would be taken. The erosion control efforts would be reactive instead of proactive, meaning that after a high intensity erosion event, only then would localized stabilization efforts occur and number of minor repairs would be conducted. The authorizing agencies overseeing such efforts would take a minimal conservation effort to reduce potentially significant impacts on the environment. Thus, more repairs will be needed annually as large and intense erosion occur, however, a number of critical sites will be left unrepaired and would likely be further eroded during severe weather patterns. If current weather trends persist, frequent and intense rain events will have higher erosion potential (Ritter and Eng, 2012), which will lead to the filling in of Lake Pepin at a rate quicker than anticipated. This would result in the need for more emergency repair each year relative to the site. Therefore, this project alternative is determined to be infeasible.

Small Scale Erosion Stabilization Project Alternative

A small scale erosion stabilization project alternative would review and authorize process to facilitate implementation of annual restoration on small erosion sites within the BERB and LSRB. A given year of stabilization projects would include a maximum of 15 individual stabilization sites that can be categorized into two tiers based on the size of the project area. The stabilization sites can be found under Objective 1. Tier 1 would include a site that is 405 m^2 or less with a maximum linear foot limit of 80 m. Tier 2 would include a site that is 2023 m^2 or less with a maximum linear foot limit of 305 m. To ensure that each project site is an unconnected single site and not part of a larger site, each site must demonstrate independent utility. Due to the sites being smaller in size, permits may not be required before construction of the stabilization project, however, each site would be evaluated and erosion control techniques would be implemented on a project to project basis.

Stabilization Techniques

Bluffs

Branch Packing

Branch packing is used to restore small, localized slumps and holes in streambanks (Eubanks and Meadows, 2002). It consists of alternating layers of live branches and compacted backfill. Branches trap sediment that refills the localized slump or hole, while roots spread throughout the backfill and into the surrounding earth to form a combined mass (Eubanks and Meadows, 2002).

Live Fascines

Live fascines are bundles of live cuttings, typically willow, bound together by rope (Prunuske et al., 1987; Gray and Sotir, 1996). They help control surface erosion, and roots from the sprouted fascines help stabilize the bank (Gray and Sotir, 1996; Eubanks and Meadows, 2002). They can be staked by themselves in shallow trenches along the contour, or used in conjunction with other bioengineering techniques for toe stabilization (Prunuske et al., 1987; Eubanks and Meadows, 2002; Pennington and Cech, 2010).

Brush Mattress

A brush mattress is a compressed layer of dormant branches that is laid on, staked and firmly secured with rope to the bank surface (Prunuske et al., 1987; Eubanks and Meadows, 2002; Charlton, 2008). The butt ends of the brush are placed in a toe trench where they can be protected by coir logs or willow wattles. If willow branches are used and the site has adequate moisture and sunlight, the branches will sprout; in shady areas, the mattress can be made with any brush and then interplanted with shade tolerant trees and shrubs (Prunuske et al., 1987). Typically, this technique is used with toe stabilization techniques such as rock, root wads, fascines, coconut fiber logs, or tree revetments (Eubanks and Meadows, 2002). Use brush mattresses on banks with slopes no greater than 2:1 (2 m in horizontal run for every 1 m of vertical rise).

Willow Walls

Willow walls are living retentive walls. Willow poles are driven into the ground and long willow branches are woven tightly between them (Prunuske et al., 1987). A natural fiber erosion control blanket and/or a layer of small brush is packed behind the wall, and the wall is then backfilled with soil (Prunuske et al., 1987). As with brush mattresses, the toe is often protected with a coir log, wattles, brush layering or loose rock. Both the poles and the woven branches sprout to form a dense willow thicket. Typically, willow walls can be implemented without professional design if the repair is only one wall high, if the height of the wall does not exceed 75 cm, and if you are able to securely key in the structure to existing stream features, such as trees (Prunuske et al., 1987). Professional help is suggested if you need a series of walls, higher walls, or for any repair requiring rock at the toe or complex key installation (Prunuske et al., 1987).

Brush Layering

Brushed layering is the technique of laying cuttings on horizontal benches that follow the contours of either an existing or filled bank slope (Prunuske et al., 1987; Gray and Sotir, 1996; Eubanks and Meadows, 2002). It is typically used on cut and fill slopes, and to repair small slumps caused by seeps (Prunuske et al., 1987). Branches serve as tensile inclusions or earth-reinforcing units to provide shallow stability of slopes (Eubanks and Meadows, 2002). The tips of the brush extend approximately 45 cm past the surface of the slope where they trap sediment and slow runoff; as the brush grows, the roots hold the soil in place (Prunuske et al., 1987; Gray and Sotir, 1996; Eubanks and Meadows, 2002). Although willows are often used for brush layering, other live woody cuttings such as dogwood *(Cornus sericea)* and cottonwood *(Populus spp.)* also sprout (Prunuske et al., 1987).

Coir logs

Coir logs are manufactured cylinders of tough coconut fiber that come in different lengths and diameters (Prunuske et al., 1987; Eubanks and Meadows, 2002). They are usually used to slow runoff and trap sediment (Koepke, 2010) and protect a bank's toe and define an edge (Eubanks and Meadows, 2002). Coir logs can be stacked and staked to provide protection in low-flow channels at the toe of banks or on gentle slopes (Prunuske et al., 1987; Koepke, 2010). Logs need to be securely staked to withstand high velocities, if they get loose in the stream, they can damage wildlife and divert flow (Prunuske et al., 1987; Eubanks and Meadows, 2002).

Fabric reinforced earth fill (FREF)

A FREF is one of the strongest bioengineering techniques. Similar to brush layering, FREFs consist of layers of fill interplanted with brush layers, however, the face of each soil lift is wrapped in coir mats to form a structure similar to a stack of quesadillas (Prunuske et al., 1987). The fabric captures the soil to provide instant erosion protection and allows FREFs to be used in situations where they will be immediately subjected to flowing water (Prunuske et al., 1987; Pennington and Cech, 2010). As the plants grow, their roots form a dense, stable matrix to create even greater protection (Pennington and Cech, 2010). A FREF must be built on a stable foundation, often rock.

Tree Revetment

Tree revetments combine traditional structural stabilization with vegetation. It creates an armored bank, and is constructed from whole trees (minus the root wad) cabled together and anchored to the bank (Prunuske et al., 1987; Eubanks and Meadows, 2002). Christmas tree revetments are those made of small trees and are generally anchored into the bank using duckbill anchors (Eubanks and Meadows, 2002). This technique is effective because it allows tree to be stacked to secure the toe, and it uses inexpensive, readily available materials to form semi-permanent protection (Eubanks and Meadows, 2002).

Vegetated boulder revetments

Vegetated boulder revetments combine traditional structural stabilization with vegetation (Prunuske et al., 1987; Charlton, 2008). Boulders are a “hard” repair and should be used only at high risk sites where conditions preclude a successful vegetation-only solution (Prunuske et al., 1987; Eubanks and Meadows, 2002; Charlton, 2008). Sprigs, poles or rooted plants are planted in between the boulders either as the revetment is being built, or plastic pipes are inserted as place holders during construction and the plants installed when the rainy season begins (Prunuske et al., 1987). Holes between the rocks can be filled with gravel and soil to improve natural revegetation (Prunuske et al., 1987).

Large Woody Debris (LWD)

LWD especially big root wads, can be used to protect banks by keeping the current off the bank and create excellent instream habitat (Prunuske et al., 1987;

Eubanks and Meadows, 2002; Parkes et al., 2003). Correct placement is critical so that the structures stay in place and function as large woody debris bank protection (Prunuske et al., 1987; Pennington and Cech, 2010). Rock or cables are sometimes used to anchor the LWD, and LWD should be used in combination with other soil bioengineering techniques to stabilize a bank (Prunuske et al., 1987; Eubanks and Meadows, 2002).

Deflectors, vanes, barbs and sills

Deflectors, vanes, barbs and sills are obstacles attached to one bank, built at right angles to the direction of the flow (Prunuske et al., 1987; Charlton, 2008). They provide local fixed points that steer flow away from eroding banks or slow it along the near bank (Prunuske et al., 1987; Charlton, 2008). At best, they are elegant repairs that buy time for the eroding sites, trapping sediment to allow vegetation to become established and secure the bank (Charlton, 2008). At worst, they can cause additional erosion by aiming flow at unprotected banks. Deflectors can be constructed of logs, rock or even willow poles and branches (Prunuske et al., 1987). Some are designed to carve pools into the channel bottom for fish habitat (Prunuske et al., 1987; Pennington and Cech, 2010). All should be securely anchored into the bank and checked frequently during the winter to make sure they are not causing unintended damage.

Grade stabilization structures

Grade stabilization structures are built to control downcutting, but their use is unsafe. Unless they are very carefully designed, they can flatten channel slopes and increase upstream channel meandering (Prunuske et al., 1987). Boulder step pools, boulder weirs or roughened rock ramps are methods that allow the stream to gradually transition from one level to the next while also allowing fish and other aquatic creatures to swim up and down the structure (Prunuske et al., 1987; Charlton, 2008; Koepke, 2010). Because of the risk of profound changes to channel stability and habitat, all grade stabilization structures should be designed by experienced river restoration managers (Prunuske et al., 1987).

Surface and subsurface flow

Excess surface runoff and subsurface water adjacent land uses to the streambank can deteriorate existing bank erosion. Surface runoff erodes the bank face, undermining the stability and armor has been placed or planted there to protect the bank. Excessive amounts of subsurface flow can saturate soils and make them far more vulnerable to outside-curve erosion and downcutting (Prunuske et al., 1987). Surface and subsurface flow can usually be controlled at the source. Roofs, foundation drains, road grading and over-irrigation are common sources of excess flow (Prunuske et al., 1987). If the source cannot be eliminated, berms can trap surface flow and subsurface drains can intercept ground water before they reach vulnerable banks. It is important to redirect the captured flow to a well-protected, non-erodible point (Prunuske et al., 1987).

Ravines

Vegetation to Prevent and Repair Erosion

Living plants provide the best erosion control in most situations. Ordinarily, plants will vegetate naturally in time (Charlton, 2008), however, to hasten vegetative

Box 1. General steps to consider for repairing most ravines: this guideline for controlling ravine erosion is adapted and summarized by Prunuske et al. (1987).

1. Try to discover why the ravine formed. If possible, address the cause. Reducing flow will reduce its erosive power.
2. Stop the headcutting. Stabilizing the ravine head will at least prevent the ravine from lengthening.
3. Restrict livestock access if the ravine is on grazing land and plant native grass and woody species wherever you can on the ravine banks. Sometimes these first three steps are enough to significantly slow the erosion and allow for the ravine to heal. If erosion is too active to allow for plants to become established, or if downcutting threatens headcut repair, move to step 4, 5, and 6, before planting.
4. Stop the downcutting. If active secondary headcuts within the ravine are not stabilized, they may creep upslope and undermine whatever work you have done upstream. Downcutting may be treated by protecting the secondary cuts just as you would the headcut and/or constructing grade stabilization structures across the floor of the ravine. Grade stabilization is tricky, thus, before installing checkdams or grade stabilization structures, seek professional advice.
5. Consider raising the level of the ravine. Checkdams are a form of grade stabilization structure that allows sediment to settle out in the slower water above the dam. Alternately, the channel can be filled behind the structure at the time of construction. As the floor of the ravine rises, the water table also rises, and the banks of the ravine become shorter and more stable. Plants are able to take root because the soil stays in place instead of continually washing away. Checkdams are best used in steep (5% slope or greater), ephemeral channels.
6. Slope the banks of the ravine back to a stable angle. With the headcutting and downcutting stabilized, this will usually occur naturally in time. However, sloping the banks allows vegetation to become established and speeds up the recovery process.
7. Revegetate the ravine with grass seed and/or other native plants. The primary purpose of the structural work is to hold the soil long enough for the plants to take over the job.

growth and to make it more effective, planting and seeding should be applied (Kraebel and Pillsbury, 1980). Restoring native plants to a disturbed area provides the raw materials for healing to continue when new erosion develops (Prunuske et al., 1987). Native grasses have deep and dense root systems, which hold the soil in place and absorb water, the leaves intercept raindrops before they hit the ground, thereby reducing their erosive force (Prunuske et al., 1987; Kraebel and Pillsbury, 1980). Although native perennial seed costs more than many of the typical introduced annual seed mixes, the long-term benefits in longevity and deep root structure may well overtake any short term savings (Prunuske et al., 1987). General steps to consider for repairing most ravines can be found in Box 1 (p.118). Guidelines for plant selection for ravine and bluff stabilization can be found in Box 2 (p. 120). A list of vascular plants found in Blue Earth County can be found in Appendix C.

In shallow ravines with low flow velocities and good sun exposure, perennial grass forms a strong, dense mat that withstands high flows (Prunuske et al., 1987; Kraebel and Pillsbury, 1980). Seed mixture that contains several kinds of grasses are recommended because they provide long-term protection and a backup in case one kind of seed does not perform well at the site flows (Prunuske et al., 1987; Kraebel and Pillsbury, 1980). Using native grass species promotes native wildlife biodiversity and creates a small reserve for these plants to spread into neighboring areas. Seed protection with mulch and a natural fiber blanket is an effective means to allow the seed to establish the root system to better hold the soil together (Prunuske et al., 1987).

Rooted native trees and shrubs can also be planted in headcuts and other ravine points, but they are not recommended for active ravines until the headcut has been stabilized with other techniques (Prunuske et al., 1987). Since trees and shrubs are best planted during the rainy season, they will not have a chance to grow strong root systems before stormflows, and unlike willows, you cannot bury 75% of their length and

Box 2. Guidelines for plant selection for ravine and bluff stabilization (Prunuske et al. 1987)

1. Use native plants that belong in the area
2. Find a reference reach in the same watershed or in a neighboring one. Reference reaches are well functioning areas where you can see which plants thrive and where they grow best.
3. Choose a variety of plants. If one is weak or slow to get started, the others can fill in. Plant diversity also increases the types of shelter and food for wildlife.
4. Be careful where you plant willow sprigs, although they provide outstanding habitat and erosion control, they can spread across channels in slow moving streams. Do not plant them in channel bottoms or near bridge or culvert openings, consider planning other willow species that grow in less aggressive, tree form.
5. Promote structural diversity to encourage bird diversity. A mixture of herbaceous plants, shrubs, and trees provide the best protection from predator and the greatest choice of nesting sites.
6. Plant the same species in clusters of 3 plants or more.
7. For stream planning, plant extra trees on the south bank to promote shade.
8. If trees do not work for the site or management needs, do not give up on planting. Grasses, sedges, and shrubs all provide excellent erosion control and important wildlife habitats.

expect them to live. Further research on deep rooted trees and shrubs are needed prior to implementation. Willow sprigs, however, are an effective and inexpensive way to soft armor active headcuts and ravine banks in small ravines, but they require soil that stay moist through the dry season (Prunuske et al., 1987). By absorbing and using water, they can help dry out an oozing headcut.

Willow Wattles, Brush Mattress, Brush Layering, or Willow Wall With or Without Shaping

These techniques, described in the bluff stabilization portion above, are excellent candidates for headcut repair. Willow wattles or fascines are best in small ravines that drain less than 2 ha; brush mattresses and brush layering can be used in larger ravines that drain under 4 ha (Prunuske et al., 1987).

Shaping and Rock

Rock is a hard armoring technique commonly used to armor headcuts and knickpoints of large and highly active ravines (Prunuske et al., 1987). Unlike purely vegetative repairs, it remains in the landscape and fixes the ravine in place (Prunuske et al., 1987; Koepke, 2010). However, there are times when rock is needed to halt severe erosion. Rock must be carefully sized and installed to stay in place during stormflows. The two most common causes of failure are piping and rock movement (Prunuske et al., 1987; Koepke, 2010). Piping occurs when water finds a cranny between the soil and the rock layer and proceeds to wash away the soil underlying the riprap (Prunuske et al., 1987). A layer of gravel or filter fabric below the rock allows water to percolate through without moving the soil. Filter fabric is easy to transport and install, but it can inhibit vegetation from becoming established between the rocks (Prunuske et al., 1987; Lenhart et al., 2010; 2011a). Generally, filter fabric is recommended for slopes steeper than 2:1 (2 m horizontal run for a 1 m vertical rise) and gravel for gentler slopes (Prunuske et al., 1987).

Shaping, Rock Riprap, and Woody Plants

Willow sprigs or other trees and shrubs planted between rocks add both wildlife value and stability to headcut repairs (Prunuske et al., 1987; Dennis, 2001; Pennington and Cech, 2010). The sprigs are best driven into the headcut and the rocks placed around carefully the sprigs for stability. Gravel works best under the rock instead of filter fabric when adding plants (Koepke, 2010), although willow sprigs can be poked through fabric on the sides of the headcut (Prunuske et al., 1987).

Diverting Flow

Diverting the water from a ravine can be an effective but risky way to reduce headcutting (Prunuske et al., 1987; Charlton, 2008). This method is best used when the ravine has been caused by channeled drainage, as in the case of a tile drainage focusing the runoff from a wide area into a narrow channel. Because rain and groundwater will collect in the ravine even if the major flow has been rerouted, the headcut will still require armoring, although it need not be as sturdy as without the diversion (Prunuske et al., 1987). Diversion alternatives include the following: 1) redistributing the runoff to better match natural runoff patterns and 2) redirecting the runoff to a different area (Prunuske et al., 1987; Charlton, 2008). Precaution must be taken with this technique because it can recreate the same issues in a new spot. Diversions should be used only when no other options are available, moreover, the runoff should be directed to a stable area, either a natural rock outcrop or an energy dissipator (Prunuske et al., 1987).

Checkdams

Checkdams or grade stabilization structure and acts as an option to slow down the flow and to raise the level of the ravine (Kraebel and Pillsbury, 1980; Prunuske et al., 1987). They decrease the velocity of the water moving down the ravine; by decreasing the velocity, silt is deposited in the ravine instead of additional material being eroded away (Kraebel and Pillsbury, 1980). They allow more control over the ravine flow and final shape, but typically require heavy equipment (Prunuske et al., 1987).

Checkdams fall into two broad categories: porous and impermeable. Porous checkdams allow water to percolate through the dam face (Prunuske et al., 1987). Sediment is deposited more slowly upstream than if the water was completely stopped, but such dams are more resistant to blowouts than impermeable dams and they are able to adjust to small changes in the shape of the gully bottom (Prunuske et al., 1987). Materials used to construct porous checkdams include strawbales, woven willow branches, brush, loose rock and logs. Impermeable checkdams include board, compacted earth, mortared rock and concrete structures (Prunuske et al., 1987). We will focus on porous dams in this report because they are safer and generally more effective over time.

Since the dams are in watercourses, avoid using toxic materials, such as creosoted railroad ties, concrete chunks or pressure-treated peeler poles (Kraebel and Pillsbury, 1980; Prunuske et al., 1987). Keep in mind that the dam will last only as long as the materials used to construct it, unless deeply-rooted vegetation is either planted in the deposited soil or allowed to grow back naturally (Kraebel and Pillsbury, 1980; Prunuske et al., 1987).

Strawbales

Strawbales are an inexpensive and relatively easy to install form of checkdam for use in mild, shallow ravines. They perform best in ravines with relatively stable sides and some existing grass cover (Prunuske et al., 1987). It is essential that vegetation be well established on the deposited sediment within that time frame because the strawbales deteriorate within 3 years (Prunuske et al., 1987). Bales should be secured into the bank with two pieces of rebar or stakes per bale (Prunuske et al., 1987). Multiple bales can be used in a row across the ravine floor.

Brush Checkdams

Brush checkdams are especially useful for hard-to-reach, small ravines with a plentiful source of woody branches nearby (Prunuske et al., 1987). Brush checkdams are usually anchored with wooden poles, preferably willow, but 2 cm rebar or steel t-posts (triangular fence posts) can also be used (Kraebel and Pillsbury, 1980). A 15-cm layer of organic litter is laid on the ravine floor both upstream and downstream of the posts, and then green branches are stacked on top of the litter, butt end upstream, packed down securely and then tied to the posts with strong rope (Prunuske et al., 1987). Longer branches should be placed on the bottom, extending further downstream, to form the energy dissipator (Prunuske et al., 1987). Leaf litter or erosion blanket is placed at the upstream end of the checkdam to catch fine sediment (Kraebel and Pillsbury, 1980).

Log Checkdams

Checkdams made from on-site logs are suitable for small ravines with a width of 91 cm or less. Unless supported with filter fabric, log dams should be used only where the runoff is rich in organic litter (Prunuske et al., 1987). Most available wood can be used, but some species rot too quickly for plants to become established. The closer the logs fit together, the more effective the dam will be in trapping sediment (Prunuske et al., 1987).

Rock grade control structures

These are constructed in large, actively eroding ravines either at grade (the same level as the existing ravine bottom) to prevent downcutting, or above grade and backfilled to restore a more stable ravine slope (Prunuske et al., 1987; Koepke, 2010). Massive materials, such as rocks used alone are dangerous because of the tendency of water to form “pipes” along the sides of the materials, which often cause the structure to be undercut, or permit flows to carry away gradually the deltas formed in times of flood (Kraebel and Pillsbury, 1980). If all of the structures needed cannot be built at one time, find a stable base point such as a flat slope, a bedrock outcrop or a culvert, and begin installing them upstream of this point so they will not be undercut as knickpoints move upstream (Prunuske et al., 1987).

Land Use Practices to Control Soil Erosion and Sediment Delivery

Conservation Tillage

A method which reduces sheet and rill erosion and increases infiltration (Waters, 1995). It is defined as a tillage system method that leaves 30% or more of the land surface covered by crop residue after planting (Waters, 1995; Czapar et al., 2006; Raven et al., 2008). Several types of conservation tillage has been developed to fit different areas of the country and different crops. One of these, no tillage, leaves the soil undisturbed over the winter (Raven et al., 2008). During planting, special machines cut a narrow furrow in the soil for seeds (Raven et al., 2008). In addition to reducing soil erosion, conservation tillage increases the organic material in the soil, which in turn improves the water holding capacity of the soil (Charlton, 2008; Raven et al., 2008).

Contouring

A method that reduces slope length, runoff and rill erosion, and promotes infiltration (Waters, 1995). It is the practice of performing field operations on the contour based on the land surface, rather than in straight rows (Waters, 1995; Czapar et al., 2006; Charlton, 2008; Raven et al., 2008). Usually there are ridges developed when the land is tilled or at planting, these ridges trap excess precipitation; when there is a mild slope to the row, the water may travel along the row to an outlet (Waters, 1995; Czapar et al., 2006; Charlton, 2008). Contouring is effective when precipitation amount, frequency, and intensities are low, when ridges are high, and when slopes and slope lengths are not excessive (Waters, 1995; Czapar et al., 2006). As slope and slope length increase, and as rainfall amount, frequency, and intensity increase, contouring loses its effectiveness and may have no impact on soil erosion.

Strip-cropping

A method that reduces slope length and runoff and promotes infiltration (Waters, 1995). Strip-cropping is a special type of contour plowing, it is the practice of growing alternative strips of different crops along the contour (Waters, 1995; Czapar et al., 2006; Raven et al., 2008). Alternating strips are crops that have different growing and harvest times. These might be a strip of row crop, with the next strip being a small grain or permanent grass. These strips reduce water erosion by being on the contour, and with runoff passing from highly erodible row crops into small grains or grass where considerable deposition may take place (Waters, 1995; Czapar et al., 2006). Even more effective control of soil erosion is achieved when strip cropping is done in conjunction with conservation tillage (Raven et al., 2008).

Grassed Waterways and grade control structures

Methods used to control channel and gully erosion (Waters, 1995). It is designed to keep erosive forces in channels carrying surface runoff below critical values where erosion might occur by devoting natural drainage routes in fields to grass turf (Waters, 1995; Czapar et al., 2006; Charlton, 2008). Water and sediment control basins are constructed basins that temporarily store runoff water and release it at controlled rates through underground drain lines (Waters, 1995). The temporary impoundment of runoff water reduces downstream runoff rates, preventing gullying and greatly reducing downstream sediment delivery (Czapar et al., 2006).

Terracing

A method used to promote infiltration, reduce slope length, runoff, and control channel and gully erosion (Waters, 1995). Terraces are broad channels graded across the steep slopes (Waters, 1995; Charlton, 2008; Raven et al., 2008). Runoff water above the terrace follows broad channels to an outlet (Czapar et al., 2006). Terraces reduce slope length and deliver surface runoff through terrace channels that are designed to be non-erodible and to prevent deposition of sediment (Waters, 1995; Czapar et al., 2006). A well designed terrace system will used grassed waterways or underground outlets to prevent channel erosion as surface runoff exits the area. Some terraces do not follow the contour, the water forms a shallow pool retaining sediment and nutrient materials, and water is stored in small impoundments until discharged through underground outlets (Czapar et al., 2006; Raven et al., 2008).

Maintenance and Monitoring

Monitoring should start before the stabilization projects with clear goals identified, and existing conditions documented. Photographic monitoring is an excellent and inexpensive way to track long-term changes. Photographs should be taken before the project begins, during the project construction, after the project is completed, and then periodically thereafter at regular intervals. Taking photographs at the same location and time each year allows accurate comparison of changes.

Once the sites are stabilized, the erosion sites would require little or no additional upkeep or maintenance. During the initial vegetation establishment period, the sites should be managed according to the vegetation management strategy. Maintenance activities for planted areas may include removing invasive vegetation, pruning planted vegetation for visibility and accessibility, and replacing dead planting. Once the final success criteria are achieved, the vegetation should be self-maintaining. Maintenance activities that focus on maintaining restoration plantings would be conducted for five years or longer as necessary until the final success criteria are met.

Potential Impacts

During the course of the stabilization project, specifically during the temporary construction portion of the project, site preparation, and material transportation, there will be a significant impact in air quality. A net increase of pollutants (NO_x, PM_{10}, $PM_{2.5}$) and green-house gas emissions, either directly, or indirectly, will come from the vehicles and machinery (bulldozers, excavators, haul trucks, barges with cranes, cement mixers, water trucks) used. These impacts are unavoidable and potentially significant. The small scale erosion projects would have a significant impact on riparian habitats and natural communities through modifications of multiple sites. It will have a substantial adverse effect on wetlands through direct removal, filling, hydrological interruption, or other means. More research is needed to determine sensitive species, either threatened, endangered or special concern, if any, are present in the site locations prior to carrying out the stabilization project.

During construction, there is a potential for temporary adverse effects on water quality, aquatic habitats, and the aquatic community. Potential impacts include sedimentation, turbidity, exposure and release of contaminants, which can affect fish population levels and survival rates. Conservation measures will need to be considered to avoid and minimize the adverse effects that could result from construction. The temporary construction disturbance could also result in the loss of individual species, or cause disruption to nesting, spawning, or migration of aquatic species. Long term, however, will provide beneficial effects for fish, wildlife, and their habits by preventing further degradation from erosion at small sites.

The small scale project will result in a significant impact on drainage, hydrology, and water quality. It may violate federal and state water quality standards, it may degrade water quality through contributions of additional sources of polluted runoff, it may create or contribute runoff water that would exceed capacity of existing drainage systems, and it may substantially affect the existing drainage pattern of the site area, or adjacent lands, including alteration of the course of streamflow, which can directly affect the site, and downstream areas. Long term effects will benefit the water quality, and the downstream areas, especially Lake Pepin through reduced sedimentation and improved water quality. Implementation of the small scale project should not result in any significant impacts on geology or soils. Further research is needed to determine if any cultural resources will be impacted.

The small scale erosion stabilization project will aim to reduce erosion from multiple sites throughout the BERB and LSRB, thus, it will be able to incorporate more socioeconomic criteria, such as threats to public and private infrastructure. Assuming no new construction will occur during the stabilization project, there will be minor impacts on existing roads, and unpaved roads due to heavy machinery use, however, there are no foreseeable impacts to buildings due to the project. Long term stabilization efforts will benefit the infrastructure through reinforcing the gradient, and stabilizing the site to prevent further degradation and erosion. Compared to the large scale project, the small scale project will be more economically beneficial in the long term. It will benefit more farmers in terms of productivity and yield as the projects will be more dispersed throughout the BERB and LSRB instead of localized like the large scale project, only benefiting one or two farmers within the stabilization project site.

Small Scale Erosion Stabilization Project Alternative Summary

Under the small scale erosion stabilization project alternative, a proactive management approach would be taken. The sites will be carefully chosen, and each criteria for the project site must be critically analyzed to determine the best approach for that specific site. The small scale erosion stabilization project will not have a greater environmental impact than the large scale stabilization project, but will have a larger economic benefit in the long term. With any environmental project, there are many variables to consider, and the GIS data for each site must be taken into account, otherwise the project will fail.

Large Scale Erosion Stabilization Project Alternative

A large scale erosion stabilization project alternative would review and authorize process to facilitate implementation of annual restoration on small erosion sites within the BERB and LSRB. A given year of stabilization projects would focus on one project up to 3 ha or 4572 linear meters in size, or a maximum of two to three individual projects of any size, as long as the maximum combined area or length permitted in that year does not exceed 3 ha or 4572 linear meters. Stabilization methods and maintenance will be similar to the Small Scale Erosion Stabilization Project. Each site would be evaluated and erosion control techniques would be implemented on a project to project basis.

Stabilization Techniques

Bluffs

Similar to the small scale erosion project alternative. (See page 111).

Ravines

Similar to the small scale erosion project alternative. (See page 117).

Maintenance and Monitoring

Similar to the small scale erosion project alternative. (See page 128).

Potential Impacts

Similar to the small scale erosion stabilization project, there will be a significant impact in air quality during the construction period. A net increase in pollutants and greenhouses gases are expected to occur, and are unavoidable. Compared to the small scale erosion stabilization project, the large scale project will have less of an impact on habitat modification. The small scale project will focus on multiple small sites, with a higher risk of habitat fragmentation, disrupting smaller areas throughout the BERB and

LSRB, whereas the large scale project will only affect one or two sites, and reduce fragmentation. However, the destruction of habitat could be exacerbated as a result of ongoing erosion during construction due to existing conditions. Like the small scale project, the large scale project will also affect wetlands through direct removal, filling, hydrological interruptions, or other means, but with a less impact than the small scale due to the lower number of sites. More research will be needed to determine if there are critically threatened or endangered species in the project area. If such species are present, effective stabilization techniques will need to be determined that will have no adverse effects on the species.

Similar to the small scale project, there is a potential for temporary adverse effects on water quality, aquatic habitats, and the aquatic community. Compared to the small scale project, the large scale project will have less of an overall impact on water quality, aquatic habitats, and the aquatic community due to the smaller number of sites disturbed. Similar to the small scale project, long term benefits to the aquatic community will be similar, if not greater due to the greater positive impact from stabilizing a larger problematic site.

Assuming that the large scale sites chosen for stabilization are the most prone to large scale erosion events, and contribute much sediments into the stream network, it has a greater amount of surface runoff than that of smaller sites. Thus, the large scale stabilization project will have a greater positive impact on drainage, hydrology and water quality than the small scale project sites. During construction, the same adverse effects will occur, however, large scale erosion project may potentially have a higher impact during construction. The large scale erosion project will focus on one or two key erosive sites, and these larger sites may require permits to stabilize. Therefore, the delay in construction will make these sites more susceptible to erosion, causing more damage and increase soil erosion. The few larger sites are highly erosive sites, and once stabilized with established vegetation, will dramatically reduce the amount of sediment eroding into the river, and will have a net positive outcome on the water quality, drainage, and hydrology. Theoretically, that should greatly reduce the rate of sedimentation of Lake Pepin, once the highly erosive sites are controlled. Further research is needed to determine if any cultural resources will be impacted.

The large scale erosion project aims to reduce erosion from key erosive sites throughout the BERB and LSRB. It will not focus as much on socioeconomic criteria when determining sites as the small scale project, but will put a greater emphasis on environmental factors and on the amount eroded into Lake Pepin. Therefore, the long-term economic benefits will not be as great or dispersed as the small scale erosion project. With the large scale erosion events, one or two key sites will be stabilized, and thus the infrastructure associated with that site will be stabilized and reinforced, however, the multiple erosive sites throughout the watershed will not be addressed as it would be in the small scale project. Therefore, economic impacts will be greater, due to the need for repair and maintenance of public and private infrastructure not associated with the stabilization site. Moreover, the economic benefits to farmers with the large scale project will not be as significant as the small scale project. The large scale project will benefit a few farmers in the long term with crop productivity and yield due to the stabilized slope no longer eroding, but other farmers throughout the watersheds not adjacent to the stabilized site will still be negatively affected.

Large Scale Erosion Stabilization Project Alternative Summary

Under the large scale erosion stabilization project alternative, a proactive management approach would be taken. The sites will be carefully chosen due to the size and amount of soil erosion, and each criteria for the project site must be critically analyzed to determine the best approach for that specific site. The large scale erosion stabilization project will not have a greater economic impact than the small scale stabilization project, but will have a larger environmental benefit in the long term. With any environmental project, there are many variables to consider, and the GIS data for each site must be taken into account, otherwise the project will fail.

Conclusions

Project Significance

This research is applicable to better stabilize and manage critically erosive sites over large spatial areas. The versatility of this GIS method can be applied to areas with multiple homologous LiDar datasets. In addition, the proposed method adapts to the changes in additional data. Once more data is acquired, the new data can be superimposed to further narrow down potential sites based on specific objectives. Lastly, this proposed method allows city planners, natural resource managers, and researchers the ability to access this file in real time in the field. The data can be covered from shape file (GIS format) to KMZ (Google Earth format) and be utilized and visible on smart phones and tablets, allowing these planners, managers, and scientists the accurate location of these sites.

Future for the BERB and LSRB

Watersheds in different regions respond variably to climate changes because runoff and other hydrologic processes are mediated through the unique combinations of the existing land cover, geology, and surface and subsurface drainage networks (Lenhart et al., 2011b). Therefore, more research is necessary to better understand sediment sources in the BERB and LSRB (MPCA, 2009). After identifying and keeping an inventory of ravines and bluffs, the next steps include long-term monitoring of TSS loads, gauging upstream and downstream of incised ravines, utilizing terrestrial laser scanning to monitor bluffs, conducting sediment budget (difference between inputs and outputs must equal any changes in storage), using mass balance to reconcile erosion estimates from different methods, and exploring the role of artificial drainage impacts on hydrology (MPCA, 2009). Local monitoring provides up to date data that can be interpolated to better understand the morphology of the ravine.

Stream gauging provides the most direct and reliable evidence of erosion rates from a watershed, methods include measurements of the rate of water flow (discharge), the river water level, and the sampling of suspended solids (MPCA, 2009). Erosion at local ravine and bluff sites can be measured through direct surveys or by changes measured on aerial photographs taken at different times (MPCA, 2009). Comparison of air photos taken at different times allows erosion to be measured over longer time periods, but generally with less precision than local measurements (MPCA, 2009).

Five basic rules when considering erosion control techniques are: 1) protect bare soil surfaces; 2) do not concentrate water flow unless absolutely necessary; 3) limit livestock and human use of vulnerable areas; 4) disturb existing vegetation as little as possible; and 5) encourage infiltration (Prunuske et al., 1987). Land areas covered by plant biomass, living or dead, are more protected and experience relatively little soil erosion because raindrop and wind energy are dissipated by the biomass later and the topsoil is held by the biomass (Prunuske et al., 1987; Arnell, 2002; Pimentel, 2006). Gravel, straw, wood chips, and other mulches are also effective. If considering the use of an impermeable substance, such as plastic sheeting, be mindful of the directed flow (Prunuske et al., 1987).

On undisturbed slopes, water percolates through soil slowly and relatively uniformly. When all the runoff from a single area is concentrated, the natural protection of the ground surface is often not sufficient to prevent the extra flow from breaking through the bare soil (Prunuske et al., 1987). If runoff should be concentrated, protect the outflow area with an energy dissipator, such as rock or securely anchored brush that can withstand heavy stormflows. Livestock and people can exacerbate mild erosion by disturbing vegetation and creating trails that channel the water flow (Prunuske et al., 1987).

Stream areas, steep or fill slopes, winter swales, unsurfaced roads, old landslides and any sites that show signs of recent soil loss are areas of special concern. Plants hold topsoil and often subsoil in place with their roots, regulate the speed of water flowing through and over soil, and provide cover for food for wildlife (Prunuske et al., 1987; Arnell, 2002). The native plant community is especially well adapted to specific soil and rainfall conditions. Once native plant cover is disturbed, the soil becomes much more susceptible to erosion (Prunuske et al., 1987; Arnell, 2002). The more water that is kept in the soil instead of on top of it, the less erosion is likely to occur (Prunuske et al., 1987). Percolation through vegetation and soil also cleans nutrients and other pollutants from water, and increases soil fertility and moisture content (Prunuske et al., 1987).

Armoring techniques include toe protection, downcutting protection, knickpoint protection, gabions, retaining walls, and rip rap, whereas native vegetation mix have been employed in various restoration projects. Stabilization techniques, whether hard armor structures and/or bioengineering and vegetative practices can fail, and therefore need to be considered with the understanding of streambank erosion and geomorphology in order to develop a successful, long term restoration plan. In Ravine 10, lack of ravine knowledge, and the sole use of hard armoring led to an unsuccessful restoration project. In Kendall County, the initial efforts did not take into account the sheer volume and velocity of the water erosion, and thus had to develop another plan that considered the ravine dynamics. Thus, when considering armoring techniques in the BERB and LSRB, sheer stress, velocity, volume, and lateral bank migration need to be considered (Koepke, 2010). When considering a bioengineering approach, soil conditions, hydrology, species selection, sunlight regime, management activities, hydroperiod return rates, and other associated factors need to be considered (Koepke, 2010).

Agricultural BMPs need to be reevaluated and applied. Improved land practices are the primary measures to directly control sediment sources: terracing, low tillage, modified cropping, reduced agricultural intensity (e.g. no till buffer zones), and wetland constructions as sediment interceptors (Waters, 1995; Czapar et al., 2006; Raven et al., 2008). Wetlands that separate upland areas from aquatic areas serve as natural filters for the runoff from adjacent land (Waters, 1995; Czapar et al., 2006). Wetlands thus serve to trap soil particles and associated agricultural contaminants. The construction of natural buffer zones and wetland replenishment are effective techniques to reduce sedimentation.

Sediments are necessary for aquatic plants and animal lives. Managed properly, sediments are a resource, improper sediment management results in the destruction of aquatic habitat that would otherwise depended on their presence. Thus, it is important that ravines and bluffs within the BERB and LSRB are identified to determine where the source of sedimentation is occurring. It is also important to use the best available science to treat and stabilize accelerated erosion in a stream system by taking into account the overall morphology of the stream and changes in the independent variables that affect the stream system (Koepke, 2010).

Future Directions

The next research steps include: conducting another LiDar flight plan, implementing a long-term monitoring plan, conduct a vegetation survey on selected sites, using terrestrial laser scanning, conduct a sediment budget, explore the role of artificial drainages, and implement BMPs. If financial opportunity exists, another congruent LiDar flight plan is suggested to gather more data to evaluate changes in the system. The collected data can be applied to the method of identify ravines and bluffs to further narrow down the inventory of erosive ravines and bluffs. Using the inventory of critical ravines and bluffs, the long term monitoring plan should include precipitation monitoring, gauging up and downstream of incised ravines to determine the TSS load and changes in water discharge, and other necessary data stated in Objective 2. This necessary data can be used in model simulations that provide information on how to better manage and stabilize these erosive sites. The selected sites for long term monitoring should include a vegetation survey that reveals the current state of nonnative and native plants within the site, and the necessary steps thereafter include removal of nonnative and invasive species, to be replaced with native plants during site stabilization. The use terrestrial laser scanning provides the ability to monitor erosive bluffs on the order of millimeters to centimeters per year. Terrestrial laser scanning collects high resolution data allowing for more accurate monitoring of erosion rates and processes, including the determination of texture and grain-size distribution (Day et al., 2013a). Similar to the LSRB, conduct a sediment budget (difference between inputs and outputs must equal any changes in storage) for the BERB to better understand the input and outputs of the watershed. It is also necessary to use a mass balance, which accounts the sediment within a specific system boundary, essentially keeping track of all the sediment that enter the system, all the sediment that leaves the system, and all of the storage within the system. Artificial drainage should also be further studies and explored to understand the impacts extensive drainage has upon the hydrology (MPCA, 2009). The last step should be implementing BMPs, whether hard physical armoring, bioengineering vegetation, or a combination of both that work with the stream to mimic and promote a stream dynamic equilibrium will help reduce and minimize sediment loading in Lake Pepin.

References:

Aksoy H., & Kavvas M.L. (2005). A review of hillslope and watershed scale erosion and sediment transport models. *Catena 64*: 247-71.

Allan, J.D. (1995). *Stream Ecology: Structure and function of running waters.* New York: Chapman & Hall.

Arekhi, S., Shabani, A., & Rostamizad, G. (2010). Application of the modified universal soil loss equation (MUSLE) in prediction of sediment yield (Case Study: Kengir Watershed, Iran). *Saudi Society for Geosciences 5*(6): 1-9.

Arnell, N. (2002). Hydrology and Global Environmental Change. New York, USA: Prentice Hall.

Arnold, J.G. (2013). Current status and future direction in watershed modeling. Retrieved from http://swat.tamu.edu/media/38819/arnold.pdf.

Arnold, J.G., & Fohrer, N. (2005). SWAT2000: current capabilities and research opportunities in applied watershed modelling. *Hydrological Processes 19*: 563-72.

Arnold, J.G., Srinivasa, R., Muttiah, R.S., & Williams, J.R. (1998). Large area hydrologic modeling and assessment part 1: Model development. *Journal of the American Water Resources Association 34*: 73-89.

Ashraf, M.I., Zhao, Z., Borque, C.P-A., & Meng, F.R. (2012). GIS-evaluation of two slope-calculation methods regarding their suitability in slope analysis using high-precision LiDAR digital elevation models. *Hydrological Processes 26*: 1119-1113.

Bailly, J-S., Kinzel, P.J., Allouis, T., Feurer, D., & Le Coarer, Y. (2012). Airborne LiDar Methods Applied to Riverine Environments. In: Carbonneau, P.E., & Piegay, H (Editors). *Fluvial Remote Sensing for Science and Management,* John Wiley & Sons, Somerset, New Jersey: 141-161.

Bauer, D.W., Mulla, D.J., & Sekeley, A.C. (2002). Streambank slumping and its contribution to the phosphorus and suspended sediment loads of the Blue Earth River, Minnesota. *Journal of Soil and Water Conservation 57*:5-243.

Belmont, P., Gran, K.B., Schottler, S.P., Wilcock, P.R., Day, S.S., Jennings, C.J., Lauer, J.W., Viparelli, E., Willenbring, J.K., Engstrom, D.R., & Parker, G. (2011). Large shift in source of fine sediment in the upper Mississippi River. *Environmental Science and Technology 45*(20):8804-8810.

Bingner, R.L., Yuan, Y., & Theurer, F.D. (2009). AnnAGPS technical processes documentation, version 5.0. USDA-ARS, National Sedimentation Laboratory, Oxford, MS.

Bhuyan, S.J., Mankin, K.R., Koelliker, J.K., Marzen, L, & Harrinton, J.A. (2001). Effect of cell size on AGNPS predictions. Paper presented at ASAE Annual International Meeting (Paper Number: 01-2002), American Association of Agricultural Engineering, Sacramento, California, 30, July-1 August.

Birtwell, I.K., Hartman, G.F., Anderson, B., McLeay, D.J., and Malick, J.G. (1984). A brief investigation of Artic grayling (*Thymallus articus)* and aquatic invertebrates in the Minto Creek drainage, Mayo, Yukon Territory: an area subjected to placer mining. *Canadian Technical Report of Fishers and Aquatic Sciences:* 1287.

Blue Earth County (2013). Expected changes to surface water, ground water, and related natural resources. *Blue Earth County Water Management Plan* pp.42-49.

Blumentritt, D.J., Wright Jr., H.E., & Stefanova, V. (2009). Formation and early history of Lakes Pepin and St. Croix of the Upper Mississippi River. *Journal of Paleolimnology 41*:545-562.

Chaplot, V. (2005). Impact of DEM mesh size and soil map precision for the prediction of water, sediment, and NO3 loads in a watershed. *Journal of Hydrology 312*:207-22.

Charlton, R. (2008). Fundamentals of Fluvial Geomorphology. New York, USA: Routledge.

Chen, R.F., Chang, K.J., Angelier, J., Chan, Y.C., Deffontaines, B., Lee, C.T., & Lin, M.L. (2006). Topographical changes revealed by high-resolution airborne LiDar data: the 1999 Tsaling landslide induced by the Chi-Chi earthquake. *Engineering Geology*: 160-172.

Cheung, A.S., & Fisher, I.H. (1995). The use of HSPF program in total catchment management. In: Proceedings of the 16th Federal Convention, AWWA, vol. 2, pp. 747-53.

Clarke, G.K.C., Leverington, D.W., Teller, J.T., & Dyke, A.S. (2004). Paleohydraulics of the last outburst flood from glacial Lake Agassiz and the 8200 BP cold event. *Quaternary Science Reviews 23*:389-407.

Czapar, G.F., Laflen, J.M., McIsaac, G.F., and McKenna, D.P. (2006). *Effects of Erosion Control Practices on Nutrient Loss*. Retrieved from http://water.epa.gov/type/watersheds/named/msbasin/upload/2006_8_25_msbasin_symposia_ia_session9.pdf.

Davenport, I.J., Silgram, M, Robinson, J.S., Lamb, A., Settle J.J., & Willig, A. (2003). The use of earth observation techniques to improve catchment scale pollution predictions. *Physics and Chemistry of the Earth 28*(33-36): 1365-76.

Day, S.S., Gran, K.B., Belmont, P., & Wawrzyniec, T. (2013a). Measuring bluff erosion part 1: terrestrial laser scanning methods for change detection. *Earth Surface Processes and Landforms 38*: 1055-67.

Day, S.S., Gran, K.B., Belmont, P., & Wawrzyniec, T. (2013b). Measuring bluff erosion part 2: pairing aerial photographs and terrestrial laser scanning to create a watershed scale sediment budget. *Earth Surface Processes and Landforms 38*: 1068-82.

Dennis, S. (2001). Natural Resources and the Informed Citizen. Chicago, Ill., USA: Sagamore Publishing.

Dillaha, T.A., Wolfe, M.L., Shirmohammadi, A., & Byne F.W. (2006) ANSWERS-2000. Paper presented at the 1998 International ASAW Meeting in Orlando, FL. (Paper number: 982199).

Di Luzio, M., Srinivasan, R., & Arnold, J.G. (2002). Integration of watershed tool and SWAT model into BASINS. *Journal of the American Water Resources Association 38*(4): 1127-41.

Douglas, E.M., Vogel, R.M., & Kroll, C.N. (2000). Trends in floods and low flows in the United States: Impact of spatial correlation. *Journal of Hydrology 240*(1-2): 90-105.

Ebisemiju, F.S., (1988). Gully morphometric controls in a laterite terrain, Guyana. *Geo Eco Trop 12*(1-4); 41-59.

Elson, J.A. (1967). Geology of glacial Lake Agassiz. In: Life, Land, and Water. University of Manitoba Press, Winnepeg, pp. 36-95.

Engstrom, D.R. (2009a). A tale of two rivers. *Journal of Paleolimnology (41):*541-543.

Engstrom, D.R., Almendinger, J.E., & Wolin, J.A. (2009b). Historical changes in sediment and phosphorus loading to the upper Mississippi River: mass-balance reconstructions from the sediments of Lake Pepin. *Journal of Paleolimnology (41):*563-588.

EPA (2015a) BASINS (Better Assessment Science Integrating Point and Nonpoint Sources). Retrieved from http://water.epa.gov/scitech/datait/models/basins/index.cfm.

EPA. (2015b). National Summary: Causes of Impairment in Assessed Rivers and Streams. Retrieved from http://iaspub.epa.gov/waters10/attains_nation_cy.control.

ESRI (2015). GIS Dictionary. Retrieved from http://support.esri.com/en/knowledgebase/GISDictionary/term/GIS.

Eubanks, C.E., & Meadows, D. (2002). A Soil Bioengineering Guide for Streambank and Lakeshore Stabilization. San Dimas, CA: USDA – Forest Service.

Faulkner, D., Larson, P.H., Jol, H.M., Running, G.L., Loope, H.M., and Goble, R.J. (submitted). Episodic Incision and Terrace Formation Resulting from Abrupt Late-Glacial Base-Level Fall, Lower Chippewa River, Wisconsin, USA. *Geomorphology*.

Fenton, M.M., Moran, S.R., Teller, J.T., & Clayton, L (1983). Quaternary stratigraphy and history in the southern part of the Lake Agassiz basin. In: Glacial Lake Agassiz, Geological Association of Canada, Special Paper 26, pp. 49-74.

Fisher, P., Abrahart, R., & Herbinger, W. (1997). The sensitivity of two distributed non-point source pollution models to the spatial arrangement of the landscape. *Hydrological Processes 11*:241-52.

Fisher, T.G. (2004). River Warren boulders, Minnesota, USA: catastrophic paleoflow indicators in the southern spillway of glacial Lake Agassiz. *Boreas 33*: 349-358.

Flanagan, D.C., & Nearing, M.A. (1995) (Eds.) USDA – Water Erosion Prediction Project: Hillslope Profile and Watershed model Documentation. NSERL Report No. 10. USDA – Agricultural Research Service, National Soil Erosion Research Laboratory, West Lafayette, Indiana.

Foster, G.R., Young, R.A., Ronkens, M.J.M., & Onstad, C.A. (1985). Processes of soil erosion by water. In: Follett, R.F., and Stewart B.A., (Editors), *Soil Erosion and Crop Productivity,* American Society of Agronomy, Crop Science Society of America, Madison, Wisconsin: 137-162.

Fu, B., Newham, L.T.H., & Ramos-Scharron, C.E. (2010). A review of surface erosion and sediment delivery models for unsealed roads. *Environmental Modelling and Software 25*:1-14.

Gassman, P.W., Williams, J.R., Benson, V.W., Izaurralde, R.C., Hauck, L.M., Allen Jones, C., Atwood, J.D., Kiniry, J.R., & Flowers, J.D. (2005). Historical development and applications of the EPIC and APEX models. Paper presented at the 2004 ASAE/CSAE annual international meeting in Ottawa, Ontario, Canada (Paper number: 042097).

Gassman, P.W., Williams, J.R., Wang, X., Saleh, A., Osei, E., Hauck, L.M., Izaurralde, R.C., & Flowers, J.D. (2010) The Agricultural Policy/Environmental eXtender (APEX) Model: An emerging tool for landscape and watershed environmental analysis. *American Society of Agricultural and Biological Engineers 53*(3): 711-40.

GBERBA (2009). Blue Earth Watershed. Retrieved from http://www.gberba.org/blueearthwatershed.htm.

GBERBA (2010). Blue Earth Watershed. Minnesota River Basin Progress Report. Retrieved from http://www.gberba.org/BlueEarthWatershedDocs/Report%20for%20blue%20earth%20from%20MN%20River%20Basin.pdf.

Gerla, P.J. (2007). Estimating the effect of cropland to prairie conversion on peak storm runoff. *Restoration Ecology 15*(4):720-730.

Gordon, L.M., Bennett, S.J., Bingner, R.L., Theurer, F.D., & Alonso, C.V. (2006). REGEM: The Revised Ephemeral Gully Erosion Model. Paper presented at the Eighth Federal Interagency Sedimentation Conference in Reno, Nevada, USA.

Govers, G., & Loch, R. (1993). Effects of initial water content and soil mechanical strength on the runoff erosion resistance of clay soils. *Australian Journal of Soil Research 31*: 549-66.

Gran, K., Belmont, P., Day, S., Jennings, C., Johnson, A., Perg, L., & Wilcock, P. (2009). Geomorphic evolution of the Le Sueur River, Minnesota, USA and implications for current sediment loading. *Special Paper 451: The Geological Society of America*, Boulder, CO: 1-12.

Gran, K., Belmont, P., Day, S., Jennings, C., Lauer, J., Viparelli, R., Wilcock, P., and Parker, G. (2011). An Integrated Sediment Budget for the Le Sueur River Basin: Final Report. Retrieved from http://www.pca.state.mn.us/index.php/view-document.html?gid=16202.

Gran, K.B., Finnegan, N., Johnson, A.L., Belmont, P., Wittkop, C., & Rittenour, T. (2013) Landscape evolution, valley excavation, and terrace development following abrupt postglacial base-level fall. *Geological Society of America Bulletin*: 1-14.

Gray, D. and Sotir, R.B. (1996). Biotechnical and Soil Bioengineering Slope Stabilization: A Practical Guide for Erosion Control. New York: John Wiley & Sons.

Gunderson, L., Finley, R., Bourne, H., and Lofton, D. (2015). Sediment Reduction Strategy for the Minnesota River basin and South Metro Mississippi River. Minnesota Pollution Control Agency Report. Pp. 1-67

Hansen, B., Lenhart, C., Mulla, D., Nieber, J., Ulrich, J., and Wing, S. (2010). *Ravine, Bluff, Streambank (RBS) erosion Study for the Minnesota River Basin).* Retrieved from the Minnesota Pollution Control Agency.

Harman, W.L., Wang, E., & Williams, J.R. (2004). Reducing atrazine losses: water quality implications of alternative runoff control practices. *Journal of Environmental Quality 33*: 7-12.

Hilliard, C., and Reedyk, S. (2014). *Soil Texture and Water Quality.* Retrieved from http://www.agr.gc.ca/eng/science-and-innovation/agricultural-practices/soil-and-land/soil-and-water/soil-texture-and-water-quality/?id=1197483793077.

Houser, J.N., Bierman, D.W., Burdis, R.M., & Soeken-Gittinger, L.A. (2010). Longitudinal trends and discontinuities in nutrients, chlorophyll, and suspended solids in the Upper Mississippi River: Implications for transport, processing, and export by large rivers. *Hydrobiological 651*:127-144.

Houser, J.N., & Richardson, W.B. (2010). Nitrogen and Phosphorus in the Upper Mississippi River: transport, processing, and effects on the river ecosystem. *Hydrobiolgia 640:* 71-88.

Inamdar, S., & Aleksey, N. (2006). Assessment of Sediment Yields for a Mixed-land use Great Lakes Watershed: Lessons from Field Measurements and Modeling. *Journal of Great Lakes Research 32*: 471-88.

Jeong, J. Kannan, N., Arnold, J.G., Glick, R., Gosselink, L., & Srinivasan, R. (2010). Development and integration of sub-hourly rainfall-runoff modeling capability within a watershed model. *Water Resource Management 24*(15): 4505-27.

Jeong, J. Kannan, N., Arnold, J.G., Glick, R., Gosselink, L., Srinivasan, R., & Barrett, M.E. (2013). Modeling sedimentation-filtration basins for urban watersheds using Soil and Water Assessment Tool. *Journal of Environmental Engineering* 838-48.

Jha, M., Gassman, P.W., Secchi, S., Gu, R., & Arnold, J.G. (2004). Effect of watershed subdivision on SWAT flow, sediment, and nutrient predictions. *Journal of the American Water Resources Association* 811-25.

Johnson, S.L. & Stefan, H.G. (2006). Indicators of climate warming in Minnesota: lake ice covers and snowmelt runoff. *Climatic Change 75*(4): 421-453.

Juracek, K.E., & Ziegler, A.C. (2009). Estimation of sediment sources using selected chemical tracers in the Perry lake basin, Kansas, USA. *International Journal of Sediment Research 24*: 108-25.

Kamalaudin, H., Lihan, T., Ali Rahman, Z., Mustapha, M.A., Idris, W.M.R., & Rahim, S.A. (2013). Integration of remote sensing, RUSLE, and GIS to model potential soil loss and sediment yield (SY). *Hydrology and Earth System Sciences 10*: 4567-96.

Karl, T.R. & Knight, R.W. (1998). Secular trends of precipitation amount, frequency, and intensity in the USA. *Bulletin of the American Meteorological Society 79*:231-241.

Kelley, D.W., & Nater, E.A. (2000a). Historical Sediment Flux from Three Watersheds into Lake Pepin, Minnesota, USA. *Journal of Environmental Quality 29*(2): 561-568.

Kelley, D.W., & Nater, E.A. (2000b). Source apportionment of lake bed sediments to watersheds in an upper Mississippi basin using a chemical mass balance method. *Catena 41*:277-92.

Kessler, A.C., Gupta, S.C., Dolliver, H.A.S., & Thoma, D.P. (2011). LiDar quantification of bank erosion in Blue Earth County, Minnesota. *Journal of Environmental Quality 41*:197-207.

Kinnell, P. & Risse, L. (1998). USLE-M: Empirical modelling rainfall erosion through runoff and sediment concentrations. *Soil Science Society of America Journal 62*(6): 1667-72.

Knisel, W.G. (1980). CREAMS: A field scale model for Chemicals, Runoff and Erosion from Agricultural Management Systems. USDA

Knox, J.C., (1987). Historical Valley Floor Sedimentation in the Upper Mississippi Valley. *Annals of the Association of American Geographers 77*(2): 224-244.

Knox, J.C. (1996). Late Quaternary Upper Mississippi River alluvial episodes and their significance to the Lower Mississippi River system. *Engineering Geology* (45)*:* 263-285.

Knox, J.C. (2001). Agricultural influence on landscape sensitivity in the Upper Mississippi River Valley. *Catena 42*: 193-224.

Koepke, J. (2010). Ravine stabilization, grade, slope, and streambank stabilization on small streams in northeast Illinois. Retrieved from http://www.ieca.org/membersonly/cms/content/Proceedings/Object576PDFEnglish.pdf.

Kumar S., Udawatta R.P., Anderson, S.H., & Mudgal, A. (2011). APEX model simulation of runoff and sediment losses for grazed pastures watersheds with agroforestry buffers. *Agroforest Systems* 83:51-62.

Kunkel, K.E., Andsager, K., & Easterling, D.R. (1999). Long-Term trends in extreme precipitation events over the conterminous United States and Canada. *Journal of Climate 12*(8): 2515-2527.

Kraebel, C.J., and Pillsbury, A.F. (1980). Handbook of Erosion Control in Mountain meadows. US Forest Service. Retrieved from http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_053967.pdf.

Lady Bird Johnson Wildflower Center at the University of Texas at Austin (2015). Native Plant Database. Retrieved from http://www.wildflower.org/plants/.

Laflen, J.M., Lane, L.J., & Foster, G.R. (1991). WEPP: A new generation of erosion prediciton technology. *Journal of Soil and Water Conservation 46*: 34-38.

Lal, R. (2010). Soil Erosion Impact on Agronomic Productivity and Environmental Quality. *Plant Sciences 17*(4): 319-464.

Lal R., & Stewart, B.A. (1990). *Soil Degradation*. New York: Spring-Verlag.

Lane, L.J., Renard, K.G., Foster, G.R., & Laflen, J.M. (1992). Development and application of modern soil erosion prediciton technology - the USDA experience. *Austrailian Journal of Soil Research 30*: 893-912.

Lane, L., Nichols, M., & Paige G. (1995). Modeling erosion on hillslopes: Concepts, theory and data. In: International Congress on Modelling and Simulation Proceedings (Agriculture, Catchment Hydrology and Industry), 1, pp 1-17.

Lenhart, C. (2012a). Restoration of the Mississippi River Gorge: Issues and Research Needs. *Ecological Restoration 30*(3): 218-227.

Lenhart, C.F., Brooks, K.N., Heneley, D., & Magner, J.A. (2009). Spatial and temporal variation in suspended sediment, organic matter, and turbidity in the Minnesota prairie river: implications for TMDLs. *Environmental Monitoring and Assessment 165*(1-4): 435-47.

Lenhart, C., Brooks, K., Magner, J., & Suppes, B. (2011a). Attenuating excessive sediment and loss of biotic habitat in an intensively managed Midwestern agricultural watershed. *Watershed Management*, 333-42.

Lenhart, C.F., Peterson, H., & Nieber, J. (2011b). Increased streamflow in agricultural watersheds of the Midwest: implications for management. *Watershed* Science, 25-31.

Lenhart, C., Suppes, B., Brooks, K., & Magner, J. (2010). Riparian corridor-channel restoration and management in Elm Creek, Minnesota. *Ecological Restoration 28*(3): 240-42.

Lenhart, C.F., Verry, E.S., Brooks, K.N., & Magner, J.A. (2012b). Adjustment of Prairie Pothole streams to land use, drainage, and climate changes and consequences for turbidity impairment. *River Research and Application 28*:1609-1619.

Lenhart, T., Eckhardt, K., Fohrer, N., & Frede, H.G. (2002). Comparison of two different approaches of sensitivity analysis. *Physics and Chemistry of the Earth 27:* 645-54.

Leopold, L.B., Wolman, M.G., & Miller, J.P. (1964). *Fluvial processes in geomorphology*. San Francisco: Freeman.

Lepper, K., Fisher, T.G., Hajdas, I., & Lowell, T.L. (2007). Ages for the Big Stone Moraine and the oldest beaches of glacial Lake Agassiz: Implications for deglaciation chronology. *The Geological Society of America 35*(7): 667-670.

Leverington, D.W., Mann, J.D., & Teller, J.T. (2002). Changes in the Bathymetry and Volume of Glacial Lake Agassiz between 9200 and 7700 ^{14}C yr B.P. *Quaternary Research 57*:244-252.

Li, R., Zhu, A.X., Song, X., Li, B., Pei, T., & Qin, C. (2012). Effects of spatial aggregation of soil spatial information on watershed hydrological modelling. *Hydrological Processes 26*: 1390-1404.

Liu, J.K., Li, R., Deshpande, S., Niu, X., & Shih, T.Y. (2009). Estimation of blufflines using topographic LiDar data and Orthoimages. *Photogrammetric Engineering & Remote Sensing 75*(1): 69-79.

Madej, M.A (2004). How Suspended Organic Sediment Affects Turbidity and Fish Feeding Behavior. Retrieved from http://soundwaves.usgs.gov/2004/11/research2.html.

Magner, J.A., & Steffen, L.J. (2000). Stream morphological response to climate and land use in the Minnesota River Basin. *Geomorphology and Restoration: Illustrated Principles*: 1-11.

Mamo, M., and Hain, P. (2005). *Impacts of Erosion on Soil, Air, and Water Quality*. Retrieved from http://passel.unl.edu/pages/informationmodule.php?idinformationmodule=1086025423&topicorder=4&maxto=20&minto=1.

Mao, D., & Cherkauer, K.A. (2008). Impacts of land-use change on hydrologic response in the Great Lakes region. *Journal of Hydrology 374*: 71-82.

Merritt, W.S., Letcher, R.A., & Jakeman, A.J. (2003). A and sediment transport models. *Environmental Modelling & Software,* 761-99.

Meybeck, M., Capman, D., and Helmer, R. (1989). *Global Freshwater Quality: A First Assessment*. Oxford: Blackwell.

Michalek, M.J. (2013). Examining the Progression and Termination of Lake Agassiz. Retrieved from https://www.msu.edu/~michal76/research/407_Geomorphology_Lake%20Agassiz2.pdf.

Miller, R.C. (1999). Hydrologic effects of wetland drainage and land use change in a tributary watershed of the Minnesota River Basin: A modeling approach. *Masters of Science Thesis. St. Paul, Minnesota: University of Minnesota-Twin Cities.*

Mishra, S.K., Tyagi, J.V., Singh, V.P., & Singh, R. (2006). SCS-CN- based modeling of sediment yield. *Journal of Hydrology 324*:301-322.

MNBWSR (2011). Blue Earth County Ravine and Stream Stabilization. Retrieved from http://www.bwsr.state.mn.us/cleanwaterfund/stories/factsheets/BlueEarth_Ravine.pdf.

MNDNR (2015a). Minnesota Native Plant Communities. Retrieved from http://www.dnr.state.mn.us/npc/index.html.

MNDNR (2015b). MNTaxa: The State of Minnesota Vascular Plant Checklist. Retrieved from http://www.dnr.state.mn.us/eco/mcbs/plant_lists.html.

MNDNR (2015c). Hydrology: Perennial Vegetation. Retrieved from http://www.dnr.state.mn.us/whaf/about/scores/hydrology/perennial.html.

MNGEO (2012). LiDAR Elevation, Blue Earth County, Minnesota, 2005. Retrieved from http://www.mngeo.state.mn.us/chouse/metadata/lidar_blueearth2005.html.

MNGEO (2014). LiDAR Elevation, Blue Earth County, Minnesota, 2012. Retrieved from http://www.mngeo.state.mn.us/chouse/metadata/lidar_blueearth2012.html.

Moore, I., & Gallant, J. (1991). Overview of hydrologic and water quality modelling. In: Moore, I. (Ed.), Modelling the Fate of Chemicals in the Environment. Centre for Resource and Environmental Studies, Australian National University, Canberra, pp. 1-8.

MPCA (2009). Identifying sediment sources in the Minnesota River Basin. *Water Quality/Basins 3.36,* pp.1-2.

MPCA (2012a). Le Sueur River Watershed Monitoring and Assessment Report. Retrieved from http://www.pca.state.mn.us/index.php/view-document.html?gid=17609.

MPCA (2012b). Turbidity Total Maximum Daily Load Study – Greater Blue Earth River Basin. Retrieved from http://www.pca.state.mn.us/index.php/view-document.html?gid=17673.

MPCA (2013). Minnesota River basin: Watonwan, Blue Earth, and Le Sueur River Watersheds. Minnesota Pollution Control Agency. Retrieved from http://www.gberba.org/BlueEarthWatershedDocs/watershed-blueearth.pdf.

MPCA (2015). Minnesota River Basin. Minnesota Pollution Control Agency. Retrieved from http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/basins/minnesota-river-basin/index.html.

MRBDC (1999). General Description of the Blue Earth River. Retrieved from http://mrbdc.mnsu.edu/sites/mrbdc.mnsu.edu/files/public/major/bluearth/data/descgen30.html.

MRBDC (2011). Minnesota River Basin Fast Facts. Minnesota River Basin Data Center. Retrieved from http://mrbdc.mnsu.edu/mnbasin/fact_sheets/fastfacts.

MRBDC (2015). MRBDC Le Sueur Major Watershed General Description. Retrieved from http://mrbdc.mnsu.edu/major/lesueur/descgen32.

Mulla D.J., & Sekely, A.C. (2009). Historical trends affecting accumulation of sediment and phosphorus in Lake Pepin, upper Mississippi River, USA. *Journal of Paleolimnology 41*(4): 589-602.

Muttiah, R.S., & Wurbs, R.A. (2002). Scale-dependent soil and climate variability effects on watershed water balance of the SWAT model. *Journal of Hydrology 256*: 264-85.

Nachtergaele, J., Poesen, J., Vandekerckhove, L., Oostwoud Wijdenes, D., & Roxo, M. (1999). Testing the Ephemeral Gully Erosion Model (EGEM) in Mediterranean Environments. Paper presented at the 1999 International Soil Conservation Organization Meeting at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory.

NCSU (2012). *Soil Erosion*. Retrieved from http://broome.soil.ncsu.edu/ssc012/Lecture/topic22.htm.

Nearing, M.A., Lane, L.J., & Lopes, V.L. (1994) Modelling soil erosion. In: Lad, R. (Editor), Soil Erosion Research Methods, pp. 127-156.

Newham, L.T.H., Prosser, I.P., Norton, J.P., Croke, B.F.W., & Jakeman, A.J. (2001). Techniques for assessing the performance of a landscape based sediment source and transport models: sensitivity trials and physical models. In: Proceedings of the International Congress on Modelling and Simulation (MODSIM' 2001), December 10-13, pp. 149-54.

Novotny, E.V., & Stefan, H.G. (2006). Stream flow in Minnesota: Indicator of climate change. *Journal of Hydrology* 344:319-333.

NRCS (2013). About RUSLE2 Technology. Retrieved from http://fargo.nserl.purdue.edu/rusle2_dataweb/About_RUSLE2_Technology.htm.

Panuska, J.C., Moore, I.D., & Kramer, L.A. (1991). Terrain analysis: integration into the Agricultural Non-Point Source (AGNPS) pollution model. *Journal of Soil Water Conservation, 46*(1):59-64.

Parkes, D., Newell, G., and Cheal, D. (2003). Assessing the quality of native vegetation; the 'habitat hectares' approach. *Ecological Management and Restoration 4*: S29-S38.

Pennington K.L. & Cech, T.V. (2010). *Introduction to Water Resources and Environmental Issues.* New York: Cambridge University Press.

Pimentel, D. (2006), Soil Erosion: A food and environmental threat. *Environment, Development, and Sustainability 8*: 119-137.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., and Blair, R. (1995). Environmental and Economics Costs of Soil Erosion and Conservation Benefits. *Science 267:*1117-1123.

Prosser, I.P., Rustomji, P., Young, B., Moran, C., & Hughes, A. (2001). Constructing river basin sediment budgets for the National Land and Water Resources Audit. Technical Report 15/01. CSIRO Land and Water, Canberra.

Prunuske, L., Choo, C., Jensen, M., and Appleton, H., (1987). Groundwork: A handbook for small-scale erosion control in coastal California. Vol. 2. Retrieved from http://www.consrv.ca.gov/dlrp/RCD/Documents/Erosion%20Control/Groundwork_4-18.pdf.

Quade, H. (2000). Blue Earth River major watershed diagnostic report. Blue Earth River Basin Implementaiton Framework. South Central Minnesota County, Comprehensive water Planning Project. Mankato, MN: Joint Powers Board and Water Resources Center, Minnesota State University.

Rahman, M. & Salbe, I. (1993). Modelling impacts of diffuse and point source nutrients on the water quality of South Creek catchment. In: International Congress on modelling and Simulation. Perth, Australia, pp. 281-87.

Raven, P., Berg, L., &. Hassenzahl, D. (2008). Environment. Hoboken, NJ, USA: John Wiley and Sons, Inc.

Raymond, P.A., David, M.B., & Saiers, J.E. (2012). The impact of fertilization and hydrology on nitrate fluxes from Mississippi watersheds. *Environmental Sustainability* (4): 212-218.

Ritter, J., & Eng, P. (2012). *Soil Erosion Causes and Effects*. Retrieved from http://www.omafra.gov.on.ca/english/engineer/facts/12-053.pdf.

Ryan, P.J., & McKenzie, N.J. (1997). Digital terrain attributes and erosion modelling for forests. In: Erosion in Forests Workshop, Cooperative Research Centre for catchment Hydrology.

Scannell, P.O. (1988). Effects of elevated sediment levels from placer mining on survival and behavior of immature Arctic grayling. Alaska Cooperative Fishery Research Unit, University of Alaska, Fairbanks, Unit Contribution 27, Fairbanks.

Schaffrath, K., Belmont, P., & Wheaton, J.M. (2015). Landscape-scale geomorphic change detection: Quantifying spatially variable uncertainty and circumventing legacy data issues. *Geomorphology 250*: 334-348.

Schottler, S.P., Engstrom, D.R., & Blumentritt, D. (2010). Fingerprinting sources of sediment in large agricultural river systems, Final Report to Minnesota Pollution Control Agency CFMS #A94798. Retrieved from http://www.smm.org/static/science/pdf/scwrs-2010fingerprinting.pdf.

Schottler, S.P., Ulrich, J., Belmont, P., Moore, R., Lauer, J.W., Engstrom, D.R., & Almendinger, J.E. (2013). Twentieth century agricultural drainage creates more erosive rivers. *Hydrological Processes*: 1-11.

Schulz, W.H. (2007). Landslide susceptibility revealed by LiDAR imagery and historical records, Seattle, Washington. *Engineering Geology 89*: 67-87.

Seeley, M., (2003). Climate trends: what are some implications for Minnesota's air and water resources? Retrieved from http://www.pca.state.mn.us/index.php/view-document.html?gid=2168.

Seeley, M. (2008). Understanding Earth's Climate and How It is Changing. *First Lego League Climate Connections* – October 16, 2008.

Sekely, A.C., Mulla, D.J., & Bauer, D.W. (2002). Streambank slumping and its contribution to the phosphorus and suspended sediment loads of the Blue Earth River, Minnesota. *Journal of Soil and Water Conservation 57*(5): 243-50.

Sepaskhah A.R., & Molodi, Z. (2003). Comparison between USLE and USLE-M for estimation of erodibility for six soil series with variable rock fragments. *Communications in Soil Science and Plant Analysis 34*(9-10): 1233-44.

Servizi, J.A, & Martens, D.W. (1992). Sublethal responses of coho salmon (*Oncorhynchus kisutch)* to suspended sediments. *Canadian Journal of Fisheries and Aquatic Sciences 49:* 1389-1395.

Shabica, C.W., Jennings, J.R., Riley, M., & Boeckler, J. (2010). Stabilization of ravines, adjacent breaches, and bluffs on Lake Michigan. *Shore and Beach 78*(1): 3-26.

Sharpley, A.N., Kleinman, P.J.A., McDowell, R.W., Gitau, M., & Bryant, R.B. (2002). Modeling phosphorus transport in agricultural watersheds: Processes and possibilities. *Soil and Water Conservation 57*(6): 425-39.

Sharpley, A.N., & Smith, S.J. (1991). Effects of cover crop on surface water quality. In: Hargrove, W.L., (Editor), *Cover crops for clean water,* Soil and Water Conservation Society, Anken, IA: 41-49.

Sharpley, A.N., & Williams, J.R. (1990). EPIC - Erosion/ Productivity Impact Calculator: Model Documentation. *U.S. Department of Agriculture Technical Bulletin No. 1768:* 235.

Shields, F.D., Knight, S.S., & Cooper, C.M. (1995). Use of index biotic integrity to assess physical habitat degradation in warmwater streams. *Hydrobiologia 312*: 191-208.

Silburn, D., & Loch, R. (1991). Evaluation of the CREAMS erosion model for predicting sediment yields and size distributions. In: Workshop on Modelling the Fate of Chemicals in the Environment, Centre for Resource and Environmental Studies, Australian National University, Canberra, pp. 141-42.

Soulsby C., Youngson, A.F., Moir, H.J., & Malcolm I.A. (2001). Fine sediment influence on salmonid spawning habitat in a lowland agricultural stream: a preliminary assessment. *Science of the Total Environment 265*: 295-307.

TAMU (2015a) APEX – Agricultural Policy/Environmental eXtender Model. Texas A&M University: Agrilife Research. Retrieved from http://epicapex.tamu.edu/apex/.

TAMU (2015b) Environmental Policy Integrated Climate (EPIC) Model. Texas A&M University: Agrilife Research. Retrieved from http://epicapex.tamu.edu/epic/.

Teller, J.T. (2001). Formation of large beaches in an area of rapid differential isostatic rebound: The three-outlet control of Lake Agassiz. *Quaternary Science Reviews 20*:1649-1659.

Teller, J.T., & Thorleifson, L.H. (1983). The Lake Agassiz – Lake Superior Connection. In: Glacial Lake Agassiz, Geological Association of Canada, Special Paper 26, pp.261-290.

Thoma, D.P., Gupta, S.C., Bauer, M.E., & Kirchoff, C.E. (2005). Airborne laser scanning for riverbank erosion assessment. *Remote Sensing of Environment 95*(4): 493-501.

Thorleifson, L.H. (1996). Review of Lake Agassiz history. Retrieved from https://www.esci.umn.edu/sites/www.esci.umn.edu/files/REVIEW%20OF%20LAKE%20AGASSIZ%20HISTORY.pdf.

Twine, T.E., Kucharik, C.J., & Foley, J.A (2004). Effects of land cover change on the energy and water balance of the Mississippi River basin. *Journal of Hydrometeorology 5*:640-655.

UBC (2015). *Soil Formation and Parent Material – Lacustrine Environment.* Retrieved from http://soilweb.landfood.ubc.ca/landscape/parent-material/water-environment/lacustrine-environment.

University of Exeter. (2007). Agricultural Soil Erosion Not Contributing To Global Warming, Study Shows. *Science Daily*. Retrieved from www.sciencedaily.com/releases/2007/10/071025143317.htm.

Uri, N.D. (2000). Agriculture and the environment – the problem of soil erosion. *Journal of Sustainable Agriculture 16*(4):71-91.

USDA (2015a). AGricultural Non-Point Source Pollution Model. Retrieved from http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/?cid=stelprdb1042468.

USDA (2015b). Native Plant Database. Retrieved from http://plants.usda.gov/java/.

USDA (2009) USLE History: Retrieved from http://www.ars.usda.gov/Research/docs.htm?docid=18093.

USDA (2010). Revised Universal Soil Loss Equation 2. Retrieved from http://www.ars.usda.gov/Research/docs.htm?docid=6027.

Vieux, B.E., & Needham, S. (1993). Nonpoint pollution model sensitive to grid cell size. *Journal of Water Resources Planning and Management 119*(2): 141-57.

Walton, R., & Hunter, H. (1996). Modelling water quality and nutrient fluxes in the Johnstone River Catchment, North Queensland. In: 23rd Hydrology and Resources Symposium, Sydney, Australia.

Wang, B., Zheng, F., Romkens, M.J.M, & Darboux, F. (2013). Soil erodibility for water erosion: A perspective and Chinese experiences. *Geomorphology 187*: 1-10.

Wang, E., Xin, C., Williams, J.R., Xu, C. (2006) Predicting soil erosion for alternative land uses. *Environmental Quality* 35: 459-67.

Wang, X., Gassman P.W., Williams, J.R., Potter, S., & Kemanian A.R. (2008). Modeling the impacts of soil management practices on runoff sediment yield maize productivity and soil organic carbon using APEX. *Soil Tillage Research* 101:78-88.

Waters, T.F. (1995) *Sediment in Streams: Sources, Biological effects and Control.* Bethesda, Maryland: American Fisheries Society.

Whittemore, R.C., & Beebe, J.A. (2000). EPA's BASINS Model: Good Science or Serendipitous Modeling? *Journal of American Water Resources Association 36*(3): 493-99.

Wilcock, P. (2010). Identifying sediment sources in the Minnesota River Basin. *Minnesota River Sediment Colloquium,* pp. 1-16.

Williams J.R. (1990). The erosion-productivity impact calculator (EPIC) model: a case history. *Philosophical Transactions: Biological Sciences 329*(1255): 421-28.

Williams J. & Steglich, E. (2009). The Texas A&M University and U.S. Bureau of Reclamation Hydrologic Modeling Inventory (HMI) Questionnaire.

Wilson, C.G., Kuhnle, D.D., Bosche, D.D., Steiner, J.L., Starks, P.F., Tomer, M.D., & Wilson, G.V. (2008). Quantifying relative contributions from sediment sources in Conservation Effects Assessment Project watersheds. *Journal of Soil and Water Conservation 63*(6): 523-31.

Wischmeier, W.H., & Smith, D.D. (1978). Predicting Soil Erosion Losses: A guide to Conservation Planning. *USDA Agricultural Handbook* No. 537:58.

Woodward, D.E. (1999). Method to predict cropland ephemeral gully erosion. *Cantena* 37(3-4): 393-99.

Wu, S.S., Usery, L.E., Finn, M.P., & Bosch D.D. (2013). An assessment of the Effects of Cell Sizes on AGNPS Modeling of Watershed Runoff. *Cartography and Geographic Information Science 35*(4): 265-78.

Ye, X., Zhang, Q., & Viney, N.R. (2011). The effect of soil data resolution on hydrological processes modelling in a large humid watershed. *Hydrological Processes 25*: 130-40.

Young, R.A., Onstad, C.A., Bosch, D.D., & Anderson, W.P. (1989). AGNPS: A non-point source pollution model for evaluating agricultural watersheds. *Journal of Soil and Water Conservation 44*(2): 168-73.

Yuan, F., Hoppie, B., Friend, D., & Lee, N. (2012). Blue Earth River quality monitoring using ARCHER hyperspectral data and field measurements. *Geocarto International*: 1-24.

Zaimes, G.N., & Schultz, R.C. (2012). Assessing riparian conservation land management practice impacts on gully erosion in Iowa. *Environmental Management 49*: 1009-21.

Zhang, L., O'Neill, A., & Lacy, S. (1995). Spatial analysis of soil erosion in catchments: a review of modelling approaches. *Water Resources and Ecology 3*: 58-64.

Zimmerman, J., Westra, R.W., & Vondracek, B. (2003). Agricultral land use effects on sediment loading and fish assemblages in tow Minnesota (USA) watersheds. *Environmental Management 32*(1): 93-105.

Appendices

Appendix A: Attributes Table Acronyms

Table 6. Acronyms and description of parameters for data tables of the potential ravine and bluff stabilization sites within Blue Earth County, Minnesota (MNGEO, 2012; MNGEO, 2014).

Soil Material Symbol	Soil Material Description
GL	Gray Lacustrine
GT	Gray Till

Soil Texture Symbol	Soil Texture Description
CL	Coarse-Loamy
F	Fine
FL	Fine-Loamy
FS	Fine-Silty
VF	Very-Fine

Land Use Symbol	Land Use Description
C	Cultivated land
DF	Deciduous Forest
EXP	Exposed Soil; Sandbars and Sand Dunes
F	Farmsteads and Rural Residences
G	Grasslands
GP	Gravel Pits and Open Mines
GTD	Grassland-Shrub-Tree (Deciduous)
OR	Other Rural Developments
RR	Rural Residential Development Complex
T	Transitional Agricultural Land
U/I	Urban and Industrial
UC	Unclassified
W	Water
WET	Wetlands

Appendix B: Model Directory

Table 7. The directory of sites to download the latest version of a specific model found in the model review. Ten of the seventeen models can be downloaded free of charge. Six of the seventeen models could not be located, and one model, SedNet was located, however required a membership, therefore the cost of that is unknown.

Model	Cost	Download
USLE	N/A	Unable to locate
USLE-M	N/A	Unable to locate
RUSLE1	Free	http://www.ars.usda.gov/Research/docs.htm?docid=7117
RUSLE2	Free	http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Program.htm
BASINS	Free	http://water.epa.gov/scitech/datait/models/basins/download.cfm
SWAT	Free	http://swat.tamu.edu/software/swat-executables/
EGEM	N/A	Unable to locate
REGEM	N/A	Unable to locate
AGNPS	Free	http://go.usa.gov/KFO
ANSWERS	N/A	Unable to locate
LISEM	Free	http://sourceforge.net/projects/lisem/
EPIC	Free	http://epicapex.tamu.edu/epic/
APEX	Free	http://epicapex.tamu.edu/apex/
CREAMS	N/A	Unable to locate
HSPF	Free	http://water.epa.gov/scitech/datait/models/basins/download.cfm
WEPP	Free	http://www.ars.usda.gov/Research/docs.htm?docid=18084
SedNet	Unknown	http://www.toolkit.net.au/tools/SedNet

Appendix C: Vascular Plants Found in Blue Earth County, Minnesota

Table 8. Vascular plants found in Blue Earth County, Minnesota (MNDNR) This table includes the USDA Plant Symbol (PS) (USDA, 2015b), Genus species (MNDNR, 2015b), Common Name (MNDNR, 2015b), Native Status (NS) (MNDNR, 2015b; USDA, 2015b), Physiognomy (P) (MNDNR, 2015b), Group (G) (USDA, 2015b), Habitat (H) (MNDNR, 2015a), Life Cycle (LC), Bloom Season (BS) (Lady Bird Johnson Wildflower Center at the University of Texas at Austin, 2015), and Plant Height (PH) (Lady Bird Johnson Wildflower Center at the University of Texas at Austin, 2015). Per the MNDNR, the scientific names in the taxa are based on the published volumes of "Flora of North America North of Mexico," (Flora of North America Editorial Committee, 1993–, Oxford University Press, New York). For species not yet published by FNA, nomenclature follows that of Gleason & Cronquist's "Manual of Vascular Plants of Northeastern United States and Adjacent Canada". There are a few exceptions to this convention for some woody species and some rare species. The superscript attached to the common name indicates a Minnesota State Rarity Status, where E – endangered; SC – special concern; T – threatened; and WL – watch list. Under the native status column, I represents an introduced species, N represents a native species, and I/N represents a species that was both introduced and native (USDA), on the contrary, the MNDNR deemed I/N as undefined. Under the Physiognomy, B represents broadleaf evergreen; D represents broadleaf deciduous; E represents needleleaf evergreen; G represents Gramminoid; H represents forb; L represents lichens and moss; C represents climber; K represents stem succulent; X represents Epiphyte; F represents floating aquatic; and S represents submerged aquatic. Under the group column, D represents dicot; F represents fern; G represents gymnosperm; H represents horsetail; L represents lycopod; and M represents monocot. Habitat was classified by the MNDNR, and data presented were conducted from native plant community surveys (MNDNR, 2015a), data gaps are for species that have not yet been surveyed in these plant communities. Classification of habitats include: CTs12 – Southern Dry Cliff; CTs33 – Southern Mesic Cliff; FFs59 – Southern Terrace Forest; FFs68 – Southern Floodplain Forest; MHs38 – Southern Mesic Oak-Basswood Forest; MHs39 - Southern Mesic Maple-Basswood Forest; MHs49 – Southern Wet-Mesic Hardwood Forest; MRp83 – Prairie Mixed Cattail Marsh; MRp93 – Prairie Bulrush-Arrowhead Marsh; OPp93 – Prairie Extremely Rich Fen; ROs12 – Southern Bedrock Outcrop; UPs13 – Southern Dry Prairie; UPs14 – Southern Dry Savanna; UPs23 – Southern Mesic Prairie; UPs24 – Southern Mesic Savanna; WMs83 – Southern Seepage Meadow/Carr; WMS93 – Southern Basic Wet Meadow/Carr; and WPs54 – Southern Wet Prairie. Under the life cycle column: A represents annual life cycle, B represents biennial life cycle, and P represents perennial life cycle. Any combination reflects as such (e.g. A/B - annual and biennial life cycle; A/P - annual and perennial life cycle, etc.).

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
ABTH	*Abutilon theophrasti*	velvet leaf	I	H	D		A	Jul-Sep	1-3 m
ACRH	*Acalypha rhomboidea*	three-seeded mercury	N	H	D	FFs68	A	Jun-Oct	20-100 cm
ACNE2	*Acer negundo*	box elder	N	D	D	FFs59; FFs68; MHs49	P	Apr-May	10-20 m
ACNI5	*Acer nigrum*	black maple	N	D	D		P	Apr-Jun	18-30 m
ACSA2	*Acer saccharinum*	silver maple	N	D	D	FFs59; FFs68	P	Mar-Apr	18-30 m
ACSA3	*Acer saccharum*	sugar maple	N	D	D	MHs38; MHs39; MHs49	P	Apr-Jun	18-30 m
ACMI2	*Achillea millefolium*	common yarrow	I/N	H	D	ROs12; UPs23; WPs54	P	Jun-Sep	30-100 cm
ACAM	*Acorus americanus*	sweet flag	N	H	M	MRp83; MRp93; WMs92	P	Jun-Jul	60-200 cm
ACRU2	*Actaea rubra*	red baneberry	N	H	D	MHs38; MHs39	P	May-Jun	30-100 cm
ADPE	*Adiantum pedatum*	maidenhair fern	N	H	F	MHs38; MHs39	P	Jun-Oct	30-60 cm
AGAU3	*Agalinis auriculata*	eared false foxglove [E]	N	H	D		A	Aug-Sep	30-100 cm
AGTE3	*Agalinis tenuifolia*	slender-leaved false foxglove	N	H	D		A	Aug-Oct	30-60 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
AGAL5	*Ageratina altissima*	white snakeroot	N	H	D	FFs68	P	Jul-Oct	30-200 cm
AGST	*Agrimonia striata*	roadside agrimony	N	H	D		P	Jul	1-2 m
AGGI	*Agrostemma githago*	common corn cockle	I	H	D		A	Jun-Aug	30-100 cm
AGGI2	*Agrostis gigantea*	redtop	I	G	M	WMs83	P	Jun-Aug	30-200 cm
AGSC5	*Agrostis scabra*	rough bentgrass	N	G	M	CTs33	P	Mar-Apr	1-2 m
ALTR7	*Alisma triviale*	northern water plantain	N	H	M	MRp93	P	Jun-Sep	1 m
ALCA3	*Allium canadense*	wild garlic	N	H	M		P	May-Jul	1-30 cm
ALAE	*Alopecurus aequalis*	short-awn foxtail	N	G	M		P	Apr	30-100 cm
AMAL	*Amaranthus albus*	tumbleweed amaranth	I	H	D		A	Apr-Oct	30-100 cm
AMBL	*Amaranthus blitoides*	prostrate pigweed	I	H	D		A	Jul-Sep	30-60 cm
AMPO2	*Amaranthus powellii*	Powell's amaranth	N	H	D		A	Jun-Dec	1-2 m
AMRE	*Amaranthus retroflexus*	redroot amaranth	N	H	D		A	Jul-Sep	1-2 m
AMTU	*Amaranthus tuberculatus*	Roughfruit amaranth	N	H	D		A	Jul-Oct	1-2 m

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
AMPS	*Ambrosia psilostachya*	western ragweed	N	H	D	UPs13; UPs14	A/P	Jul-Oct	30-100 cm
AMTR	*Ambrosia trifida*	great ragweed	N	H	D		A	Jul-Sep	1-4 m
AMHU2	*Amelanchier humilis*	low juneberry	N	D	D	UPs14; UPs24	P	Apr-May	30-100 cm
AMIN2	*Amelanchier interior*	inland juneberry	N	D	D		P	May-Jun	1-2 m
AMSA	*Amelanchier sanguinea s.s.*	round-leaved juneberry	N	D	D		P	May-Jun	1-3 m
AMCO	*Ammannia coccinea*	ammannia	N	H	D		A	Jul-Sep	20-100 cm
AMCA6	*Amorpha canescens*	leadplant	N	D	D	UPs13; UPs14; UPs23; UPs24	P	Jun-Aug	30-100 cm
AMFR	*Amorpha fruticosa*	false indigo	N	D	D		P	Jun-Jul	1-4 m
AMNA	*Amorpha nana*	fragrant false indigo	N	D	D		P	Jun-Jul	30-60 cm
AMBR2	*Amphicarpaea bracteata*	hog peanut	N	H	D	FFs59; MHs38	A/P	Jul-Sep	30-200 cm
ANGE	*Andropogon gerardii*	big bluestem	N	G	M	OOp93; ROs12; UPs13; UPs14; UPs23; UPs24; WPs54	P	Jul-Aug	60-300 cm
ANOC2	*Androsace occidentalis*	western androsace	N	H	D	ROs12	A	Apr-May	1-8 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
ANCA8	*Anemone canadensis*	canada anemone	N	H	D	UPs23; WPs54	P	May -Jul	30-60 cm
ANCA9	*Anemone caroliniana*	Carolina thimbleweed	N	H	D		P	Apr-May	7-15 cm
ANCY	*Anemone cylindrica*	long-headed thimbleweed	N	H	D	UPs13; UPs14; UPs23	P	Jun-Aug	30-60 cm
ANPA19	*Anemone patens*	pasqueflower	N	H	D	UPs13	P	Mar - May	7-45 cm
ANQU	*Anemone quinquefolia*	wood anemone	N	H	D	MHs38; MHs39	P	Apr-Jun	1-30 cm
ANVI3	*Anemone virginiana*	tall thimbleweed	N	H	D		P	Jun-Aug	30-100 cm
ANGR2	*Anethum graveolens*	dill	I	H	D		A	Jul-Sep	30-100 cm
ANHO	*Antennaria howellii*	Howell's pussytoes	N	H	D		P	Apr-Jun	30-100 cm
ANNE	*Antennaria neglecta s.s.*	field pussytoes	N	H	D		P	Apr-Jun	10-40 cm
ANPA9	*Antennaria parlinii*	Parlin's pussytoes	N	H	D		P	Mar -Apr	1-30 cm
ANPL	*Antennaria plantaginifolia s.s.*	plantain-leaved pussytoes	N	H	D	UPs13	P	Apr-Jun	10-40 cm
ANCO2	*Anthemis cotula*	dog fennel	I	H	D		A	Jun-Oct	30-60 cm
ANHIA	*Anthoxanthum hirtum*	sweet grass	N	G	M		P	May -Jul	60-100 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
APAM	*Apios americana*	groundnut	N	H	D		P	Jul-Sep	1-30 cm
APHY	*Aplectrum hyemale*	puttyroot	N	H	M		P	May	1-100 cm
APAN2	*Apocynum androsaemifolium*	spreading dogbane	N	H	D		P	Jun-Aug	30-100 cm
APCA	*Apocynum cannabinum*	American hemp	N	H	D		P	May - Aug	1-2 m
APOCY	*Apocynum sibiricum*	clasping dogbane	N	H	D	OOp93; UPs23; WMs92; WPs54	P	Jun-Aug	30-200 cm
AQCA	*Aquilegia canadensis*	columbine	N	H	D	CTs33	P	Feb-Jul	30-100 cm
ARHI	*Arabis pycnocarpa*	hairy rock cress	N	H	D	CTs33	A/B/P	May -Jul	20-100 cm
ARUN2	*Aralia nudicaulis*	wild sarsaparilla	N	H	D	MHs38	P	May -Jun	20-100 cm
ARRA	*Aralia racemosa*	American spikenard	N	H	D		P	Jul	1-3 m
ARMI2	*Arctium minus*	common burdock	I	H	D		B	Jul-Aug	30-300 cm
ARDR3	*Arisaema dracontium*	green dragon [SC]	N	H	M	FFs68	P	May -Jul	30-100 cm
ARTR	*Arisaema triphyllum*	Jack-in-the-pulpit	N	H	M	FFs59; MHs38; MHs39; MHs49	P	Apr-Jun	30-100 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
ARBA2	*Aristida basiramea*	base-branched three-awn	N	G	M		A	Aug-Oct	1-100 cm
ARDI4	*Aristida dichotoma*	churchmouse three-awn	N	G	M		A	Jun-Aug	30-60 cm
ARPU9	*Aristida purpurea*	red three-awn	N	G	M		A/P	Apr-Oct	30-100 cm
ARRU4	*Armoracia rusticana*	horseradish	I	H	D		P	May-Aug	30-200 cm
ARPL4	*Arnoglossum plantagineum*	tuberous Indian plantain [T]	N	H	D		P	Jun-Aug	1-2 m
ARBI2	*Artemisia biennis*	biennial wormwood	I/N	H	D		A/B	Jul-Oct	30-60 cm
ARCA12	*Artemisia campestris*	field sagewort	N	H	D	UPs14	B/P	Jul-Aug	1-30 cm
ARDR4	*Artemisia dracunculus*	tarragon	N	H	D	UPs13; UPs14	P	Jul-Sep	60-200 cm
ARLU	*Artemisia ludoviciana*	white sage	I/N	H	D	UPs13; UPs14; UPs23; UPs24	P	Jul-Aug	30-100 cm
ASCA	*Asarum canadense*	wild ginger	N	H	D	CTs33; MHs38; MHs39; MHs49	P	Apr-May	10-30 cm
ASIN	*Asclepias incarnata*	swamp milkweed	N	H	D	MRp83; MRp93; OOp93; WMs83; WMs92; WPs54	P	Jun-Aug	30-100 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
ASSU3	*Asclepias sullivantii*	Sullivant's milkweed [T]	N	H	D		P	Jun-Aug	60-100 cm
ASSY	*Asclepias syriaca*	common milkweed	N	H	D	UPs14; UPs23	P	Jun-Aug	60-200 cm
ASTU	*Asclepias tuberosa*	butterflyweed	N	H	D		P	Jun-Aug	30-200 cm
ASVE	*Asclepias verticillata*	whorled milkweed	N	H	D	UPs13	P	Jul-Sep	30-60 cm
ASVI	*Asclepias viridiflora*	green milkweed	N	H	D	UPs13	P	Jun-Aug	30-100 cm
ASOF	*Asparagus officinalis*	asparagus	I	H	M		P	May-Jun	30-200 cm
ASRH2	*Asplenium rhizophyllum*	walking fern	N	H	F	CTs33	P	Jun-Oct	5-30 cm
ASAG2	*Astragalus agrestis*	fieldmilk-vetch	N	H	D		P	Jun-Jul	15-30 cm
ASCA11	*Astragalus canadensis*	Canada milk-vetch	N	H	D		P	Jun-Aug	30-100 cm
ASCR2	*Astragalus crassicarpus*	ground plum	N	H	D	UPs23	P	May-Jun	30-100 cm
ATFI	*Athyrium filix-femina*	common ladyfern	N	H	F	MHs38; MHs39	P	Jul-Aug	30-200 cm
ATPA4	*Atriplex patula*	spearscale	I	H	D		A	Oct	30-200 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
ATPR	*Atriplex prostrata*	thinleaf orach	N	H	D		A	Jun-Oct	30-100 cm
AVSA	*Avena sativa*	cultivated oats	I	G	M		A	May -Jul	30-100 cm
BAVU	*Barbarea vulgaris*	yellow rocket	I	H	D		B	May -Jul	30-100 cm
BETH	*Berberis thunbergii*	Japanese barberry	I	D	D		P	May	30-300 cm
BEVU	*Berberis vulgaris*	common barberry	I	D	D		P	May	30-300 cm
BEIN2	*Berteroa incana*	hoary alyssum	I	H	D		A/B/P	Oct	30-100 cm
BEER	*Berula erecta*	stream parsnip [T]	N	H	D		P	Jul-Sep	30-100 cm
BEAL2	*Betula alleghaniensis*	yellow birch	N	D	D		P	Apr-May	21-30 m
BEPA	*Betula papyrifera*	paper birch	N	D	D	MHs38	P	May	21-30 m
BICE	*Bidens cernua*	nodding bur marigold	N	H	D	FFs68; MRp83; MRp93; WMs92	A	Aug -Oct	30-100 cm
BICO5	*Bidens connata*	swamp beggarticks	N	H	D	FFs68; MRp83; MRp93; WMs92	A	Aug -Oct	20-200 cm
BIFR	*Bidens frondosa*	leafy beggarticks	N	H	D	FFs68; MRp83; MRp93; WMs92	A	Jul-Oct	30-100 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
BITR	*Bidens tripartita*	tufted beggarticks	N	H	D	FFs68; MRp83; MRp93; WMs92	A	Aug -Sep	15-200 cm
BOCA11	*Boechera canadensis*	sicklepod	N	H	D		B	May -Jul	30-100 cm
BODE3	*Boechera dentata*	stellate rock cress	N	H	D		B/P	Apr-May	20-100 cm
BOGR6	*Boechera grahamii*	spreading rock cress	N	H	D		B/P	May -Jul	25-100 cm
BOCY	*Boehmeria cylindrica*	false nettle	N	H	D	FFs68	P	Jul-Sep	40-100 cm
BOFL3	*Bolboschoenus fluviatilis*	river bulrush	N	G	M	MRp83; MRp93; WMs92	P	Jul	30-200 cm
BOAS	*Boltonia asteroides*	false aster	N	H	D		P	Jul-Oct	1-2 m
BOVI	*Botrychium virginianum*	rattlesnake fern	N	H	F	MHs38; MHs39	P	Sep-Nov	30-100 cm
BOCU	*Bouteloua curtipendula*	side-oats grama	N	G	M	UPs13; UPs14; UPs23; UPs24	P	Jul-Sep	30-100 cm
BOGR2	*Bouteloua gracilis*	blue grama	N	G	M	UPs13	P	Jul-Oct	30-100 cm
BOHI2	*Bouteloua hirsuta*	hairy grama	N	G	M	ROs12; UPs13; UPs14	P	Mar - May	30-100 cm
BRER2	*Brachyelytrum erectum s.s.*	bearded shorthusk	N	G	M	MHs38	P	Jun-Aug	30-60 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
BRNI	*Brassica nigra*	black mustard	I	H	D		A	Jun-Sep	1-2 m
BRRA	*Brassica rapa*	field mustard	I	H	D		A/B	May -Jun	30-200 cm
BREU	*Brickellia eupatorioides*	false boneset	N	H	D	UPs13	P	May -Oct	30-200 cm
BRIN2	*Bromus inermis*	smooth brome	I/N	G	M		P	May -Jul	30-100 cm
BRKA2	*Bromus kalmii*	Kalm's brome	N	G	M		P	Jun-Aug	30-100 cm
BRLA4	*Bromus latiglumis*	broad-glumed brome	N	G	M		P	Jun-Aug	30-200 cm
BRTE	*Bromus tectorum*	cheatgrass	I	G	M		A	May -Jun	30-60 cm
BUCA2	*Bulbostylis capillaris*	densetuft hairsedge	N	G	M		A/P	Jun-Oct	1-30 cm
CACA4	*Calamagrostis canadensis*	bluejoint	N	G	M	MHs49; MRp83; WMs83; WMs92; WPs54	P	Jun-Aug	1-2 m
CAST36	*Calamagrostis stricta*	slimstem reedgrass	N	G	M	MRp83; OOp93; WMs83; WPs54	P	Mar -Oct	30-100 cm
CALO	*Calamovilfa longifolia*	prairie sandreed	N	G	M	UPs13; UPs14	P	Jul-Aug	1-3 m
CAPA5	*Caltha palustris*	common marsh marigold	N	H	D	WMs83; WMs92	P	Apr-May	30-100 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
CASE12	*Calylophus serrulatus*	toothed evening primrose	N	H	D	UPs13; UPs23	P	Jun-Aug	30-60 cm
CASE13	*Calystegia sepium*	hedge bindweed	I/N	H	D	MRp93	P	Jun-Sep	1-3 m
CAMI2	*Camelina microcarpa*	small-seeded false flax	I	H	D		A/B	May - Aug	30-100 cm
CAAM18	*Campanula americana*	tall bellflower	N	H	D	FFs68	A	Jul-Sep	60-200 cm
CAAP2	*Campanula aparinoides*	marsh bellflower	N	H	D	MRp83; OOp93; WMs83; WMs92	P	Jun-Aug	7-100 cm
CARO2	*Campanula rotundifolia*	harebell	N	H	D	CTs33; ROs12; UPs13; UPs14	P	Jun-Oct	15-50 cm
CASA3	*Cannabis sativa*	marijuana	I	H	D		A	Jul-Aug	30-300 cm
CABU2	*Capsella bursa-pastoris*	shepherd's-purse	I	H	D		A	Jan-Oct	30-60 cm
CABU3	*Cardamine bulbosa*	spring cress	N	H	D		P	Apr-Jun	20-100 cm
CACO26	*Cardamine concatenata*	cut-leaved toothwort	N	H	D	MHs39; MHs49	P	Apr-May	20-40 cm
CAPE3	*Cardamine pensylvanica*	Pensylvania bitter cress	N	H	D		A/B/P	Apr-Jun	15-50 cm
CAAL11	*Carex albursina*	white bear sedge	N	G	M	MHs49	P	Apr-Jun	1-30 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
CAAL8	*Carex alopecoidea*	foxtail sedge	N	G	M		P	Jul	30-100 cm
CAAN6	*Carex annectens*	yellow-fruit sedge [SC]	N	G	M		P	Jul-Aug	30-100 cm
CAAS2	*Carex assiniboinensis*	assiniboine sedge	N	G	M		P	Jun-Sep	30-100 cm
CAAT2	*Carex atherodes*	slough sedge	N	G	M	MRp83; WMs92	P	May-Jul	30-100 cm
CABE2	*Carex bebbii*	Bebb's sedge	N	G	M		P	Jun-Jul	30-100 cm
CABI3	*Carex bicknellii*	Bicknell's sedge	N	G	M	ROs12	P	Mar-May	30-100 cm
CABL	*Carex blanda*	charming sedge	N	G	M	MHs39	P	Mar-Jun	30-100 cm
CABR10	*Carex brevior s.s*	shortbeak sedge	N	G	M	ROs12	P	Jun-Jul	30-200 cm
CACE2	*Carex cephaloidea*	cluster bracted sedge	N	G	M		P	Apr-Jul	30-200 cm
CACE	*Carex cephalophora*	oval-headed sedge	N	G	M		P	May-Jul	30-100 cm
CACO8	*Carex comosa*	bristly sedge	N	G	M		P	Apr-Jul	30-100 cm
CACR7	*Carex cristatella*	crested sedge	N	G	M		P	May-Jun	30-100 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
CADE9	*Carex deweyana*	Dewey's sedge	N	G	M		P	Mar -Jul	30-100 cm
CADU6	*Carex duriuscula*	spike rush sedge	N	G	M	ROs12	P	Jun-Aug	1-30 cm
CAEB2	*Carex eburnea*	ivory sedge	N	G	M	CTs33; CTs53	P	May -Jul	1-30 cm
CAEM2	*Carex emoryi*	Emory's sedge	N	G	M		P	Jul-Aug	60-200 cm
CAGR2	*Carex gracillima*	graceful sedge	N	G	M		P	Jun-Jul	20-100 cm
CAGR3	*Carex granularis*	granular sedge	N	G	M		P	Apr-Jul	30-60 cm
CAGR4	*Carex gravida*	heavy sedge	N	G	M		P	May	30-100 cm
CAGR24	*Carex grisea*	ambiguous sedge	N	G	M	FFs59; FFs68; MHs49	P	May -Jun	30-100 cm
CAHI5	*Carex hirtifolia*	hairy-leaved sedge	N	G	M	MHs49	P	May -Jul	30-60 cm
CAHI8	*Carex hitchcockiana*	Hitchcock's sedge	N	G	M		P	May	30-60 cm
CAHY4	*Carex hystericina*	porcupine sedge	N	G	M	MRp83; WMs83	P	May -Jun	1-10 cm
CAIN11	*Carex interior*	interior sedge	N	G	M	OOp93; WMs83	P	Apr-May	30-100 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
CALA16	*Carex lacustris*	lake sedge	N	G	M	MRp83; MRp93; WMs83; WMs92	P	May-Jun	30-200 cm
CALA12	*Carex laeviconica*	smooth-cone sedge	N	G	M		P	May-Jul	30-100 cm
CALE10	*Carex leptalea*	bristle-stalked sedge	N	G	M		P	Mar-Sep	30-100 cm
CALU14	*Carex lupulina*	hop umbrella sedge	N	G	M	FFs68	P	Mar-May	30-100 cm
CAME2	*Carex meadii*	Mead's sedge	N	G	M		P	Mar-May	30-60 cm
CAMO11	*Carex molesta*	troublesome sedge	N	G	M		P	May-Jun	30-100 cm
CAPE11	*Carex peckii*	Peck's sedge	N	G	M		P	May-Jun	20-45 cm
CAPE4	*Carex pedunculata*	long-stalked sedge	N	G	M	MHs38; MHs39	P	Apr-Jul	1-30 cm
CAPE42	*Carex pellita*	woolly sedge	N	G	M	MRp83; MRp93; WMp73; WMs83; WMs92; WPs54	P	May-Jun	15-100 cm
CAPE6	*Carex pensylvanica*	Pennsylvania sedge	N	G	M	MHs38; MHs39; UPs14	P	May-Jun	10-45 cm
CAPR6	*Carex prairea*	prairie sedge	N	G	M	OOp93; WMs83	P	Jun-Aug	30-100 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
CARA8	*Carex radiata*	eastern star sedge	N	G	M		P	Apr-May	30-100 cm
CARO22	*Carex rosea*	starry sedge	N	G	M	FFs59; MHs38; MHs39	P	Apr-May	30-100 cm
CASA8	*Carex sartwellii*	Sartwell's sedge	N	G	M	MRp93; OOp93; WMp73; WMs83	P	Jun-Jul	30-200 cm
CASA9	*Carex saximontana*	Rocky Mountain sedge	N	G	M		P	May	1-60 cm
CASC11	*Carex scoparia*	pointed broom sedge	N	G	M	MRp93	P	Apr-May	30-100 cm
CASP3	*Carex sparganioides*	bur-reed sedge	N	G	M		P	May-Jun	30-100 cm
CASP7	*Carex sprengelii*	Sprengel's sedge	N	G	M	MHs49	P	Jun-Jul	30-100 cm
CAST5	*Carex stipata*	awl-fruited sedge	N	G	M	WMs83	P	Jun	30-200 cm
CAST8	*Carex stricta*	tussock sedge	N	G	M	MRp83; OOp93; WMp73; WMs83; WMs92; WPs54	P	May-Jun	30-100 cm
CATE6	*Carex tetanica*	rigid sedge	N	G	M	OOp93; WPs54	P	Mar-May	30-60 cm
CATU2	*Carex tuckermanii*	Tuckerman's sedge	N	G	M		P	Jun-Aug	30-200 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
CAVE6	*Carex vesicaria*	inflated sedge	N	G	M		P	Jun	30-200 cm
CAVU2	*Carex vulpinoidea*	fox sedge	N	G	M		P	May-Jul	30-100 cm
CACA18	*Carpinus caroliniana*	blue beech	N	D	D	MHs38; MHs39; MHs49	P	Apr-May	6-12 m
CACA19	*Carum carvi*	caraway	I	H	D		B/P	May-Jun	30-60 cm
CACO15	*Carya cordiformis*	bitternut hickory	N	D	D	FFs59; MHs38; MHs39; MHs49	P	Apr-May	15-25 m
CASE5	*Castilleja sessiliflora*	downy paintbrush	N	H	D		P	May-Jul	10-30 cm
CATH2	*Caulophyllum thalictroides*	blue cohosh	N	H	D	MHs38; MHs39; MHs49	P	May	30-100 cm
CEAM	*Ceanothus americanus*	American New Jersey tea	N	D	D		P	Jul-Sep	30-100 cm
CESC	*Celastrus scandens*	climbing bittersweet	N	C	D		P	May-Jun	3-10 m
CEOC	*Celtis occidentalis*	hackberry	N	D	D	FFs59; FFs68; MHs49	P	Aug	21-30 m
CELO3	*Cenchrus longispinus*	sandbur	N	G	M		A	Jun-Aug	30-100 cm
CEBR3	*Cerastium brachypodum*	short-stalked chickweed	N	H	D		P	Apr-Jun	1-30 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
CEFO2	*Cerastium fontanum*	mouse-ear chickweed	I	H	D		B/P	May -Sep	1-60 cm
CEDE4	*Ceratophyllum demersum*	common coontail	N	H; S	D	MRp83; MRp93	P	Jun-Sep	1-3 m
CHMI	*Chaenorhinum minus*	dwarf snapdragon	I	H	D		A	Jun-Oct	1-30 cm
CHFA2	*Chamaecrista fasciculata*	partridge pea	N	H	D		A	Jun-Oct	1-30 cm
CHGL2	*Chelone glabra*	white turtlehead	N	H	D	WMs83	P	Jul-Sep	1-2 m
CHAL7	*Chenopodium album s.s.*	white lamb's quarters	I/N	H	D		A	Jun-Oct	1-2 m
CHGL3	*Chenopodium glaucum*	oak-leaved goosefoot	I	H	D		A	Jul-Oct	1-30 cm
CHST2	*Chenopodium standleyanum*	woodland goosefoot	N	H	D		A	Sep	1-60 cm
CIBU	*Cicuta bulbifera*	bulb-bearing water hemlock	N	H	D	MRp93; WMs83; WMs92	P	Jul-Sep	30-200 cm
CIMA2	*Cicuta maculata*	spotted water hemlock	N	H	D	MRp93; WMs83; WMs92; WPs54	B/P	Jun-Aug	1-2 m
CIAR2	*Cinna arundinacea*	stout woodreed	N	G	M	FFs68	P	Jun-Aug	1-2 m
CIAL	*Circaea alpina*	small enchanter's nightshade	N	H	D		P	Jun-Aug	7-30 cm
CILU	*Circaea lutetiana*	broadleaf enchanter's nightshade	N	H	D	FFs59; MHs38; MHs39; MHs49	P	Jun-Aug	30-60 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
CIAR4	*Cirsium arvense*	Canada thistle	I	H	D		P	Jul-Aug	30-200 cm
CIDI	*Cirsium discolor*	field thistle	N	H	D		B/P	Jul-Oct	1-3 m
CIFL	*Cirsium flodmanii*	Flodman's thistle	N	H	D	UPs13; UPs23	P	Jun-Aug	30-100 cm
CIMU	*Cirsium muticum*	swamp thistle	N	H	D	OOp93; WMs83; WPs54	B	Jul-Oct	1-3 m
CLVI3	*Claytonia virginica*	Virginia spring beauty	N	H	D	MHs49	P	Apr-Jun	7-15 cm
CLVI5	*Clematis virginiana*	virgin's bower	N	H	D	CTs33	P	Jul-Sep	2-3 m
COVI6	*Coeloglossum viride*	long-bracted orchid	N	H	M		P	May-Aug	15-50 cm
COLI2	*Collomia linearis*	linear-leaved collomia	N	H	D		A	May-Aug	30-90 cm
COUM	*Comandra umbellata*	bastard toadflax	N	H	D	ROs12; UPs13; UPs14; UPs23	P	May-Jul	7-30 cm
COAR4	*Convolvulus arvensis*	field bindweed	I	H	D		P	Jun-Oct	10-100 cm
COCA5	*Conyza canadensis*	horseweed	N	H	D	UPs14	A/B	Jul-Oct	15-200 cm
CORA4	*Conyza ramosissima*	spreading fleabane	N	H	D		A	May-Sep	1-30 cm
COTR2	*Coptis trifolia*	goldthread	N	H	D		P	May-Jun	7-15 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
COPA10	*Coreopsis palmata*	bird's foot coreopsis	N	H	D	UPs13; UPs14; UPs23; UPs24	P	Jun-Aug	30-100 cm
COTI3	*Coreopsis tinctoria*	plains coreopsis	N	H	D		A/B/P	Jul-Sep	1-2 m
COAL2	*Cornus alternifolia*	pagoda dogwood	N	D	D	MHs38; MHs39; MHs49	P	May-Jun	7-100 cm
COAM2	*Cornus amomum*	silky dogwood	N	D	D		P	Jun-Jul	2-4 m
CORA6	*Cornus racemosa*	gray dogwood	N	D	D	UPs24	P	Jun-Jul	1-3 m
CORU	*Cornus rugosa*	round-leaved dogwood	N	D	D		P	Jun-Jul	2-4 m
COSE16	*Cornus sericea*	red-osier dogwood	N	D	D	OOp93; WMs83; WMs92; WPs54	P	May-Aug	1-3 m
COAU2	*Corydalis aurea*	golden corydalis	N	H	D		A/B	May-Jul	1-30 cm
COMI2	*Corydalis micrantha*	smallflower fumewort	N	H	D		A	Feb-Apr	30-100 cm
COAM3	*Corylus americana*	American hazelnut	N	D	D	MHs38; UPs14; UPs24	P	Apr-Jun	2-4 m
CRMO2	*Crataegus mollis*	downy hawthorn	N	D	D	FFs59; MHs49	P	May-Jun	10-22 m
CRPU	*Crataegus punctata*	dotted hawthorn	N	D	D	FFs59; MHs49	P	May-Jun	10-22 m
CRST2	*Cryptogramma stelleri*	slender cliff brake	N	H	F	CTs53	P	Mar-Aug	1-30 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
CRCA9	*Cryptotaenia canadensis*	honewort	N	H	D	FFs59; FFs68; MHs38; MHs39; MHs49	P	Jun-Jul	30-100 cm
CUCE	*Cuscuta cephalanthi*	buttonbush dodder	N	H	D	FFs68	P	Jul-Aug	1-2 m
CUCO3	*Cuscuta coryli*	hazel dodder	N	H	D	FFs68	P	Jul-Sep	DH
CUPE3	*Cuscuta pentagona*	bur clover dodder	N	H	D	FFs68	A/P	Jul-Aug	1-2 m
CYXA2	*Cyclachaena xanthifolia*	marsh elder	N	H	D		A	Aug -Oct	60-200 cm
CYOF	*Cynoglossum officinale*	hound's tongue	I	H	D		B	May -Jun	15-120 cm
CYBI6	*Cyperus bipartitus*	brook nut sedge	N	G	M		A	Jul-Aug	5-30 cm
CYDI3	*Cyperus diandrus*	sedge galingale	N	G	M		A	Jun-Aug	5-25 cm
CYER2	*Cyperus erythrorhizos*	red-rooted cyperus	N	G	M		A/P	Jul-Aug	1 m
CYES	*Cyperus esculentus*	yellow nutsedge	I/N	G	M		P	Jul-Aug	30-60 cm
CYLU2	*Cyperus lupulinus*	slender nut sedge	N	G	M		P	Jun-Oct	10-50 cm
CYOD	*Cyperus odoratus*	fragrant cyperus	N	G	M		A/P	Aug -Sep	30-120 cm
CYSQ	*Cyperus squarrosus*	awned umbrella sedge	N	G	M		A	Jun-Aug	2-10 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
CYST	*Cyperus strigosus*	straw-colored umbrella sedge	N	G	M		P	Jun-Sep	20-90 cm
N/A	*Cyperus X mesochorus*	Midland sand sedge	N	G	M		P	Jul-Sep	30-60 cm
CYCA5	*Cypripedium candidum*	small white lady's slipper SC	N	H	M		P	May-Jun	10-40 cm
CYPA19	*Cypripedium parviflorum*	yellow lady's slipper	N	H	M		P	Apr-Jun	10-70 cm
CYBU3	*Cystopteris bulbifera*	bulblet fern	N	H	F	CTs33	P	Jun-Sep	20-30 cm
CYTE7	*Cystopteris tenuis*	Macay's brittle fern	N	H	F		P	Jun-Oct	30-40 cm
DAGL	*Dactylis glomerata*	orchard grass	I	G	M		P	Mar-May	40-100 cm
DAPU5	*Dalea purpurea*	purple prairie clover	N	H	D	UPs13; UPs14; UPs23; UPs24; WPs54	P	Jun-Sep	20-90 cm
DECA3	*Delphinium carolinianum*	Carolina larkspur	N	H	D		P	Feb-Jun	40-90 cm
DEPI	*Descurainia pinnata*	pinnate tansy mustard	N	H	D		A/B/P	Feb-Apr	10-60 cm
DESO2	*Descurainia sophia*	herb sophia	I	H	D		A/B	May-Sep	20-70 cm
DEIL	*Desmanthus illinoensis*	prairie mimosa SC	N	H	D		P	May-Jul	50-100 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
DECA7	*Desmodium canadense*	Canada tick trefoil	N	H	D	UPs23; WPs54	P	Jul-Aug	60-180 cm
DEGL5	*Desmodium glutinosum*	pointed-leaved tick trefoil	N	H	D	MHs38	P	May-Jul	30-120 cm
DICU	*Dicentra cucullaria*	dutchman's breeches	N	H	D	MHs39; MHs49	P	May	10-20 cm
DIAC2	*Dichanthelium acuminatum*	hairy panic grass	N	G	M	ROs12	P	Feb-Nov	15-40 cm
DILE2	*Dichanthelium leibergii*	Leiberg's panic grass	N	G	M	UPs23	P	May-Sep	25-75 cm
DIOL	*Dichanthelium oligosanthes*	Scribner's panic grass	N	G	M	ROs12; UPs13; UPs14	P	Apr-Oct	15-85 cm
DIOV	*Dichanthelium ovale*	long-haired panic grass	N	G	M		P	Mar-May	30-100 cm
DILI2	*Dichanthelium perlongum*	long-stalked panic grass	N	G	M		P	May-Oct	30-100 cm
DILO	*Diervilla lonicera*	bush honeysuckle	N	D	D		P	Jun-Aug	30-100 cm
DIIS	*Digitaria ischaemum*	smooth crabgrass	I	G	M		A	Oct	10-35 cm
DISA	*Digitaria sanguinalis*	hairy crabgrass	I	G	M		A	Jul-Oct	10-30 cm
DIPA9	*Dirca palustris*	leatherwood	N	D	D		P	Mar-Jun	1-4 m
DISP	*Distichlis spicata*	salt grass	N	G	M		P	Apr-Oct	1-30 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
DOUM2	*Doellingeria umbellata*	flat-topped aster	N	H	D	OOp93; WMs83; WPs54	P	Aug-Sep	50-200 cm
DRRE2	*Draba reptans*	Carolina whitlow grass	N	H	D		A	Feb-Jun	5-15 cm
DRRO	*Drosera rotundifolia*	round-leaved sundew	N	H	D		P	Jun-Sep	5-30 cm
DRCA11	*Dryopteris carthusiana*	spinulose shield fern	N	H	F		P	Jul-Aug	30-100 cm
DRCR4	*Dryopteris cristata*	crested fern	N	H	F		P	May-Aug	30-100 cm
DRGO3	*Dryopteris goldiana*	Goldie's fern SC	N	H	F		P	Jun-Jul	35-120 cm
DUAR3	*Dulichium arundinaceum*	three-way sedge	N	G	M		P	Jul-Aug	30-200 cm
ECCR	*Echinochloa crus-galli*	cockspur barnyard grass	I	G	M		A	Jul-Oct	30-120 cm
ECMU2	*Echinochloa muricata*	rough barnyard grass	N	G	M		A	Jul-Oct	1-2 m
ECLO	*Echinocystis lobata*	wild cucumber	N	H	D	FFs68	A	Jun-Oct	6-8 m
ELAC	*Eleocharis acicularis*	least spikerush	N	G	M		A/P	Apr-Sep	1-30 cm
ELCO2	*Eleocharis compressa*	flattened spikerush	N	G	M	OOp93; WPs54	P	May	10-45 cm
ELEL4	*Eleocharis elliptica*	elliptic spikerush	N	G	M		P	May-Aug	30-100 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
ELER	*Eleocharis erythropoda*	bald spikerush	N	G	M		P	Jun-Aug	30-100 cm
ELOV	*Eleocharis ovata s.s.*	ovoid spikerush	N	G	M	MRp93	A	Jun-Nov	30-100 cm
ELPA3	*Eleocharis palustris s.s.*	marsh spikerush	N	G	M	MRp83; MRp93; OOp93; WMs83; WMs92	P	Jun-Aug	30-100 cm
ELNY	*Ellisia nyctelea*	ellisia	N	H	D		A	Apr-Jun	20-30 cm
ELBI2	*Elodea bifoliata*	two leaf waterweed E	N	H; S	M		P	Jul-Oct	4-24 cm
ELCA7	*Elodea canadensis*	Canadian elodea	N	H; S	M		P	Jun-Aug	1-8 cm
ELNU2	*Elodea nuttallii*	Nuttall's elodea	N	H; S	M		P	Jun-Aug	1-8 cm
ELCA4	*Elymus canadensis*	canada wild rye	N	G	M	CTs12	P	Mar-Jun	1-2 m
ELHY	*Elymus hystrix*	bottlebrush grass	N	G	M	MHs38; MHs39; MHs49	P	Jun-Aug	1-2 m
ELRE4	*Elymus repens*	quackgrass	I	G	M		P	Jun-Aug	30-120 cm
ELTR7	*Elymus trachycaulus*	slender wheatgrass	N	G	M	UPs23	P	Jun-Jul	30-100 cm
ELVI	*Elymus villosus*	downy wild rye	N	G	M		P	Jul	1-2 m
ELVI3	*Elymus virginicus*	Virginia wildrye	N	G	M	FFs59; FFs68	P	Mar-May	1-2 m

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
ENBI	*Enemion biternatum*	false rue anemone	N	H	D	FFs59; MHs39; MHs49	P	Mar - May	30-100 cm
EPCO	*Epilobium coloratum*	purple-leaved willow herb	N	H	D	MRp93; WMs83	P	Jun-Aug	30-120 cm
EPLE2	*Epilobium leptophyllum*	linear-leaved willow herb	N	H	D	WMs83; WMs92	P	Jun-Aug	10-100 cm
EQAR	*Equisetum arvense*	field horsetail	N	H	H	WPs54	P	Mar - May	5-60 cm
EQFL	*Equisetum fluviatile*	water horsetail	N	H	H	MRp83	P	Apr-May	35-115 cm
EQHY	*Equisetum hyemale*	scouringrush horsetail	N	H	H		P	Jan-Dec	1-2 m
EQLA	*Equisetum laevigatum*	smooth scouring rush	N	H	H	WPs54	P	Mar -Apr	20-150 cm
EQPR	*Equisetum pratense*	meadow horsetail	N	H	H		P	Apr-May	30-100 cm
EQSC	*Equisetum scirpoides*	dwarf scouring rush	N	H	H		P	Jun-Aug	1-30 cm
ERCI	*Eragrostis cilianensis*	stink grass	I	G	M		A	Jul-Oct	10-90 cm
ERHY	*Eragrostis hypnoides*	creeping lovegrass	N	G	M		A	Jun-Sep	10-25 cm
ERPE	*Eragrostis pectinacea*	tufted lovegrass	N	G	M		A/P	Mar -Sep	30-100 cm
ERSP	*Eragrostis spectabilis*	purple lovegrass	N	G	M	UPs14	P	Mar - May	40-75 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
ERHI12	*Erechtites hieraciifolius*	pilewort	N	H	D		A	Jul-Sep	60-250 cm
ERAN	*Erigeron annuus*	annual fleabane	N	H	D		A	Jun-Aug	60-150 cm
ERPH	*Erigeron philadelphicus*	Philadelphia fleabane	N	H	D		B/P	Mar -Jun	5-70 cm
ERST3	*Erigeron strigosus*	daisy fleabane	N	H	D	ROs12; UPs13; UPs23	A/B/P	May -Jun	30-70 cm
ERVI3	*Eriochloa villosa*	hairy cupgrass	I	G	M		A	Apr-May	60-90 cm
ERAN6	*Eriophorum angustifolium*	tall cottongrass	N	G	M	OOp93	P	Apr-May	20-100 cm
ERCH7	*Eriophorum chamissonis*	Chamisso's cottongrass	N	G	M		P	Jun-Aug	30-70 cm
ERGR8	*Eriophorum gracile*	slender cottongrass	N	G	M		P	Jun-Aug	20-60 cm
ERYU	*Eryngium yuccifolium*	rattlesnake master SC	N	H	D	UPs23	P	Jul-Sep	80-120 cm
ERCH9	*Erysimum cheiranthoides*	wormseed mustard	I	H	D		A/B	May -Sep	15-100 cm
ERIN7	*Erysimum inconspicuum*	small-flowered wallflower	N	H	D		B/P	Apr-Aug	15-70 cm
ERAL9	*Erythronium albidum*	white trout lily	N	H	M	MHs39; MHs49	P	Apr-May	10-20 cm
EUAT5	*Euonymus atropurpureus*	wahoo	N	D	D		P	Apr-Jun	6-7.5 m

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
EUAL3	*Eupatorium altissimum*	tall boneset	N	H	D		P	Sep-Oct	50-150 cm
EUPE3	*Eupatorium perfoliatum*	common boneset	N	H	D	MRp83; OOp93; WMs83	P	Jul-Oct	40-100 cm
EUCY	*Euphorbia cyathophora*	painted leaf	N	H	D		A/P	May-Nov	30-100 cm
EUCY2	*Euphorbia cyparissias*	cypress spurge	I	H	D		P	May-Sep	20-40 cm
EUDE4	*Euphorbia dentata*	toothed spurge	N	H	D		A	Jul-Sep	1-60 cm
EUES	*Euphorbia esula*	leafy spurge	I	H	D		P	May-Jul	30-60 cm
EUGL3	*Euphorbia glyptosperma*	ridge-seeded spurge	N	H	D		A	Jun-Nov	5-15 cm
EUMA7	*Euphorbia maculata*	prostrate hairy spurge	N	H	D		A	Jun-Sep	5-15 cm
EUNU	*Euphorbia nutans*	nodding spurge	N	H	D		A/P	Jul-Nov	30-100 cm
EUSE5	*Euphorbia serpyllifolia*	thyme-leaved spurge	N	H	D		A	Aug-Sep	5-15 cm
EUGR5	*Euthamia graminifolia*	grass-leaved goldenrod	N	H	D	OOp93; WPs54	P	Jul-Sep	1-2 m
EUMA9	*Eutrochium maculatum*	spotted Joe pye weed	N	H	D	OOp93; WMs83; WMs92	P	Aug-Oct	1-4 m
EUPU21	*Eutrochium purpureum*	sweet-scented Joe pye weed	N	H	D		P	Jul-Sep	1-2 m

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
FACO	*Fallopia convolvulus*	black-bindweed	I	H	D		A	Jul-Oct	50-100 cm
FASC	*Fallopia scandens*	false buckwheat	N	H	D		P	Jul-Sep	1-4.5 m
FESU3	*Festuca subverticillata*	nodding fescue	N	G	M	MHs38	P	Apr-Jun	50-100 cm
FRVE	*Fragaria vesca*	wood strawberry	N	H	D		P	May-Aug	5-30 cm
FRVI	*Fragaria virginiana*	common strawberry	N	H	D	UPs23; WPs54	P	Apr-Jun	1-30 cm
FRNI	*Fraxinus nigra*	black ash	N	D	D	FFs59; MHs39; MHs49	P	Mar-Apr	10-22 m
FRPE	*Fraxinus pennsylvanica*	green ash	N	D	D	FFs59; FFs68; MHs38; MHs39; MHs49	P	Apr-Jun	10-22 m
FRFL	*Froelichia floridana*	prairie cottonweed	N	H	D		A	Jun-Aug	1-1.8 m
GASP5	*Galearis spectabilis*	showy orchis	N	H	M		P	Apr-Jun	7-25 cm
GAPA2	*Galinsoga parviflora*	gallant soldier	I	H	D		A	Jul-Sep	10-60 cm
GAAP2	*Galium aparine*	cleavers	N	H	D	FFs59; MHs38; MHs39; MHs49	A	May-Jun	10-100 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
GABO2	*Galium boreale*	northern bedstraw	N	H	D	CTs33; OOp93; ROs12; UPs23; UPs24; WPs54	P	Jun-Aug	30-100 cm
GACO3	*Galium concinnum*	shining bedstraw	N	H	D	MHs38	P	Jun-Aug	2-8 m
GAOB	*Galium obtusum*	bluntleaf bedstraw	N	H	D		P	Jun-Jul	20-75 cm
GATI	*Galium tinctorium*	stiff bedstraw	N	H	D	MRp83	P	Jun-Sep	25-45 cm
GATR3	*Galium triflorum*	sweet-scented bedstraw	N	H	D	FFs59; MHs38; MHs39; MRp83	P	May-Aug	15-75 cm
GEAN	*Gentiana andrewsii*	bottle gentian	N	H	D	WPs54	P	Aug-Sep	30-60 cm
GEAL4	*Gentiana flavida*	yellowish gentian	N	H	D		P	Aug-Oct	30-100 cm
GEPU5	*Gentiana puberulenta*	downy gentian	N	H	D		P	May-Sep	1-30 cm
GEPR6	*Gentianopsis procera*	lesser fringed gentian	N	H	D	OOp93	A	Aug-Sep	7-45 cm
GEMA	*Geranium maculatum*	wild geranium	N	H	D	FFs59; MHs38; MHs39; MHs49	P	May-Jun	30-60 cm
GEAL3	*Geum aleppicum*	yellow avens	N	H	D		P	Jul-Oct	30-100 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
GECA7	*Geum canadense*	white avens	N	H	D	FFs59; MHs38; MHs39; MHs49	P	May-Jul	30-100 cm
GLHE2	*Glechoma hederacea*	creeping charlie	I	H	D		P	Apr-Jun	10-20 cm
GLGR	*Glyceria grandis*	american manna grass	N	G	M	MRp83; MRp93; WMs92	P	Jun-Aug	90-160 cm
GLST	*Glyceria striata*	fowl manna grass	N	G	M	OOp93; WMs83; WPs54	P	Jul-Aug	40-90 cm
GLLE3	*Glycyrrhiza lepidota*	wild licorice	N	H	D		P	Jun-Jul	30-100 cm
GRSQ	*Grindelia squarrosa*	curly cup gumweed	N	H	D		A/B/P	Jun-Sep	40-100 cm
GYDI	*Gymnocladus dioicus*	Kentucky coffee tree SC	N	D	D		P	Jun	20-30 m
HADE	*Hackelia deflexa*	nodding stickseed	N	H	D	FFs68	A/B/P	May-Jul	60-100 cm
HAVI2	*Hackelia virginiana*	Virginia stickseed	N	H	D	FFs68	B/P	Jun-Aug	60-100 cm
HEHI	*Hedeoma hispida*	mock pennyroyal	N	H	D	ROs12; UPs13; UPs14	A	May-Jul	7-40 cm
HELO7	*Hedyotis longifolia*	bluets	N	H	D	ROs12	P	Jun-Aug	7-25 cm
HEAU	*Helenium autumnale*	autumn sneezeweed	N	H	D	WPs54	P	Aug-Oct	50-130 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
HEBI2	*Helianthemum bicknellii*	hoary frostweed	N	H	D	ROs12; UPs14	P	May -Jul	20-60 cm
HEAN3	*Helianthus annuus*	common sunflower	N	H	D		A	Jul-Oct	40-250 cm
HEGR4	*Helianthus grosseserratus*	sawtooth sunflower	N	H	D	WMs83; WPs54	P	Aug - Nov	1-4 m
HEHI2	*Helianthus hirsutus*	hairy sunflower	N	H	D		P	Aug - Nov	1-2 m
HEMA 2	*Helianthus maximiliani*	Maximilian's sunflower	N	H	D	UPs23; UPs24; WPs54	P	Aug - Nov	1-2 m
HEPA1 9	*Helianthus pauciflorus*	stiff sunflower	N	H	D	UPs13; UPs14; UPs23; UPs24	P	Jul-Sep	30-180 cm
HEPE	*Helianthus petiolaris*	prairie sunflower	N	H	D		A	Jun-Sep	40-200 cm
HETU	*Helianthus tuberosus*	Jerusalem artichoke	N	H	D		P	Aug -Oct	50-300 cm
HEHE5	*Heliopsis helianthoides*	smooth oxeye	N	H	D	UPs23	P	Jun-Sep	80-120 cm
HEMA 80	*Heracleum lanatum*	cow parsnip	N	H	D	FFs59	P	May -Jul	1-3 m
HEMA 3	*Hesperis matronalis*	dame's rocket	I	H	D		B/P	May -Jul	60-100 cm
HESP1 1	*Hesperostipa spartea*	porcupine grass	N	G	M	UPs13; UPs14; UPs23; UPs24	P	Mar - May	60-100 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
HERI	*Heuchera richardsonii*	alumroot	N	H	D	CTs12; UPs23	P	May-Jul	30-60 cm
HITR	*Hibiscus trionum*	flower-of-an-hour	I	H	D		A	Jul-Sep	10-60 cm
HIUM	*Hieracium umbellatum*	rough hawkweed	N	H	D		P	Jun-Sep	30-150 cm
HOJU	*Hordeum jubatum*	foxtail barley	N	G	M	WMp73	P	Jun-Aug	30-75 cm
HULU	*Humulus lupulus*	common hops	I/N	H	D		P	Jul-Oct	1-4 m
HUPO2	*Huperzia porophila*	rock fir moss T	N	H	L		P	May-Jul	10-15 cm
HYVI	*Hydrophyllum virginianum*	Virginia waterleaf	N	H	D	FFs59; MHs38; MHs39; MHs49	P	May-Jun	30-75 cm
HYMA2	*Hypericum majus*	large St. John's-wort	N	H	D		A	Jun-Sep	50-75 cm
HYAS80	*Hypericum pyramidatum*	great St. John's-wort	N	H	D		P	Jul-Aug	60-150 cm
HYHI2	*Hypoxis hirsuta*	yellow star-grass	N	H	M	WPs54	P	May-Jul	20-25 cm
IMCA	*Impatiens capensis*	spotted touch-me-not	N	H	D	FFs59; FFs68; MHs39; MHs49; MRp93; WMs83; WMs92	A	Jul-Sep	60-150 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
IMPA	*Impatiens pallida*	pale touch-me-not	N	H	D	FFs59; FFs68; MHs39; MHs49; MRp93; WMs83; WMs92	A	Jul-Sep	60-200 cm
IRVE2	*Iris versicolor*	northern blue flag	N	H	M		P	May - Aug	30-100 cm
IRVI	*Iris virginica*	southern blue flag	N	H	M	FFs68; MRp93	P	Jun-Jul	60-100 cm
ISBR3	*Isanthus brachiatus*	false pennyroyal	N	H	D		A	Aug -Sep	20-40 cm
JUCI	*Juglans cinerea*	butternut E	N	D	D	MHs49	P	May -Jun	6-24 m
JUNI	*Juglans nigra*	black walnut	N	D	D	FFs59	P	Apr-May	11-35 m
JUAR2	*Juncus arcticus*	artic rush	I/N	G	M	WPs54	P	Jul-Aug	30-100 cm
JUBR	*Juncus brachycarpus*	short-fruited rush	N	G	M		P	May -Jun	30-100 cm
JUDU2	*Juncus dudleyi*	Dudley's rush	N	G	M		P	Jun-Aug	20-100 cm
JUNO2	*Juncus nodosus*	knotty rush	N	G	M		P	Jun-Sep	5-70 cm
JUTE	*Juncus tenuis*	path rush	N	G	M		P	Jun-Sep	15-50 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
JUTO	*Juncus torreyi*	Torrey's rush	N	G	M		P	Jul-Aug	40-100 cm
JUCO6	*Juniperus communis*	common juniper	N	E	G	CTs12	P	Apr-May	5-8 m
JUVI	*Juniperus virginiana*	eastern red cedar	N	E	G	ROs12	P	Mar - May	10-22 m
KOSC	*Kochia scoparia*	summer cypress	I	H	D		A	Jul-Sep	30-120 cm
KOMA	*Koeleria macrantha*	junegrass	N	G	M	UPs13; UPs14	P	Jun	10-60 cm
LABI	*Lactuca biennis*	biennial blue lettuce	N	H	D		A/B	Jul-Oct	75-200 cm
LACA	*Lactuca canadensis*	Canada wild lettuce	N	H	D		A/B	Jun-Oct	40-200 cm
LALU	*Lactuca ludoviciana*	Louisiana lettuce	N	H	D		B/P	Jun-Sep	15-150 cm
LASE	*Lactuca serriola*	prickly lettuce	I	H	D		A/B	Jul-Sep	30-70 cm
LACA3	*Laportea canadensis*	woodnettle	N	H	D	FFs59; FFs68; MHs39; MHs49	P	Jul-Sep	40-100 cm
LARE	*Lappula redowskii*	western stickseed	I	H	D		A	Mar -Jun	10-45 cm
LASQ	*Lappula squarrosa*	two-row stickseed	I	H	D		A/B	May -Jul	20-60 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
LAOC2	*Lathyrus ochroleucus*	pale vetchling	N	H	D		P	May -Jul	30-100 cm
LAPA4	*Lathyrus palustris*	marsh vetchling	N	H	D	WMs83; WMs92; WPs54	P	Jun-Jul	30-120 cm
LAVE	*Lathyrus venosus*	veiny pea	N	H	D	WPs54	P	May -Jul	30-100 cm
LEST	*Lechea stricta*	prairie pinweed	N	H	D	UPs14	P	May -Jul	30-100 cm
LEOR	*Leersia oryzoides*	rice cut grass	N	G	M	FFs68; MRp93	P	Jul-Oct	30-120 cm
LEVI2	*Leersia virginica*	white grass	N	G	M	FFs59; FFs68	P	Aug -Sep	50-120 cm
LEMI3	*Lemna minor s.s.*	lesser duckweed	N	F; H	M	MRp83	P	Jun-Aug	1-7 cm
LETR	*Lemna trisulca*	star duckweed	N	F; H	M	MRp83	P	Apr-May	1-10 cm
LETU2	*Lemna turionifera*	turion duckweed	N	F; H	M		P	Jun-Aug	1-10 mm
LECA2	*Leonurus cardiaca*	common motherwort	I	H	D		P	Jun-Aug	60-120 cm
LEDE	*Lepidium densiflorum*	green-flowered peppergrass	I/N	H	D	ROs12	A/B	May -Jul	30-60 cm
LEDR	*Lepidium draba*	hoary cress	I	H	D		P	May -Jul	20-65 cm
LECA8	*Lespedeza capitata*	round-headed bush clover	N	H	D	ROs12; UPs14	P	Jul-Sep	60-150 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
LEVU	*Leucanthemum vulgare*	ox-eye daisy	I	H	D		P	Jun-Aug	30-100 cm
LIAS	*Liatris aspera*	rough blazing star	N	H	D	UPs13; UPs14; UPs23; UPs24	P	Jul-Sep	30-120 cm
LILI	*Liatris ligulistylis*	northern plains blazing star	N	H	D	UPs23; WPs54	P	Jul-Oct	20-100 cm
LIPU	*Liatris punctata*	dotted blazing star	N	H	D	UPs13	P	Jul-Oct	15-85 cm
LIPY	*Liatris pycnostachya*	prairie blazing star	N	H	D	UPs23; WPs54	P	Jun-Aug	60-120 cm
LIMI9	*Lilium michiganense*	Michigan lily	N	H	M		P	Jun-Jul	1.5 -2 m
LIPH	*Lilium philadelphicum*	wood lily	N	H	M	UPs23; WPs54	P	May - Aug	80-120 cm
LIVU2	*Linaria vulgaris*	butter-and-eggs	I	H	D		P	Jun-Oct	30-60 cm
LIDU	*Lindernia dubia*	yellow-seeded false pimpernel	N	H	D		A/B	Jul-Sep	5-20 cm
LIUS	*Linum usitatissimum*	common flax	I	H	D		A	Apr-May	30-120 cm
LILO	*Liparis loeselii*	Loesel's twayblade	N	H	M		P	May - Aug	7-25 cm
LIMI12	*Lipocarpha micrantha*	hemicarpha	N	G	M		A	Aug -Oct	1-15 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
LICA12	*Lithospermum canescens*	hoary puccoon	N	H	D	UPs13; UPs14; UPs23	P	May - Aug	15-45 cm
LICA13	*Lithospermum caroliniense*	hairy puccoon	N	H	D	UPs13; UPs14	P	May -Jul	15-60 cm
LIIN2	*Lithospermum incisum*	narrow-leaved puccoon	N	H	D	UPs13	P	Apr-Jun	10-40 cm
LILA2	*Lithospermum latifolium*	American gromwell	N	H	D		P	May -Jun	40-75 cm
LOKA	*Lobelia kalmii*	Kalm's lobelia	N	H	D	OOp93	P	Jul-Sep	10-40 cm
LOSI	*Lobelia siphilitica*	great lobelia	N	H	D	WPs54	P	Jul-Oct	30-120 cm
LOSP	*Lobelia spicata*	pale-spiked lobelia	N	H	D	UPs23; WPs54	P	Jun-Aug	30-60 cm
LOPE	*Lolium perenne*	English rye grass	I	G	M		A/P	Jun-Oct	30-90 cm
LOOR	*Lomatium orientale*	desert parsley	N	H	D		P	Mar -Jun	15-25 cm
LODI2	*Lonicera dioica*	wild honeysuckle	N	C	D		P	Jun-Jul	1-3 m
LYAM	*Lycopus americanus*	cut-leaved bugleweed	N	H	D	FFs68; MRp83; MRp93; OOp93; WMs83; WMs92; WPs54	P	Jul-Sep	15-75 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
LYAS	*Lycopus asper*	rough bugleweed	N	H	D	MRp83; WMs83; WMs92; WPs54	P	Jul-Sep	15-90 cm
LYUN	*Lycopus uniflorus*	northern bugleweed	N	H	D	FFs68; MRp83; MRp93; OOp93; WMs83	P	Jul-Sep	15-75 cm
LYJU	*Lygodesmia juncea*	skeletonweed	N	H	D		P	Jun-Sep	10-35 cm
LYCI	*Lysimachia ciliata*	fringed loosestrife	N	H	D	MRp83	P	Jun-Aug	30-120 cm
LYQU	*Lysimachia quadriflora*	prairie loosestrife SC	N	H	D	OOp93; WPs54	P	Jul-Aug	30-100 cm
LYTE2	*Lysimachia terrestris*	yellow loosestrife	N	H	D		P	Jun-Aug	30-100 cm
LYTH2	*Lysimachia thyrsiflora*	tufted loosestrife	N	H	D	MRp83; MRp93; WMs83; WMs92	P	May-Jul	30-100 cm
LYAL4	*Lythrum alatum*	wing-angled loosestrife	N	H	D		P	Jun-Sep	30-120 cm
MACA4	*Maianthemum canadense*	Canada mayflower	N	H	M	MHs38	P	May-Jun	5-15 cm
MARA7	*Maianthemum racemosum*	common false Solomon's seal	N	H	M	MHs38; MHs39; MHs49	P	May-Jun	30-100 cm
MAST4	*Maianthemum stellatum*	starry false Solomon's seal	N	H	M	FFs59; UPs14; WMs83	P	May-Jun	30-75 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
MANE	*Malva neglecta*	cheeses	I	H	D		A/B/P	May -Oct	15-30 cm
MAPU5	*Malva rotundifolia*	round-leaved mallow	I	H	D		A/B	May -Oct	15-30 cm
MADI6	*Matricaria discoidea*	pineapple weed	I	H	D		A	Jun-Oct	4-40 cm
MAST	*Matteuccia struthiopteris*	ostrich fern	N	H	F	FFs59	P	Jun-Aug	60-180 cm
MELU	*Medicago lupulina*	black medick	I	H	D		A/P	May -Sep	5-75 cm
MESA	*Medicago sativa*	alfalfa	I	H	D		A/P	Jun-Sep	30-100 cm
MEAL2	*Melilotus alba*	white sweet clover	I	H	D		A/B/P	Jun-Oct	60-250 cm
MEOF	*Melilotus officinalis*	yellow sweet clover	I	H	D		A/B/P	Jun-Sep	60-180 cm
MECA3	*Menispermum canadense*	Canada moonseed	N	C	D	FFs59; FFs68; MHs39	P	May -Jul	2-7 m
MEAR4	*Mentha arvensis*	wild mint	N	H	D	FFs68; MRp83; MRp93; WMs83; WMs92	P	Jul-Sep	15-50 cm
METR3	*Menyanthes trifoliata*	buckbean	N	H	D		P	Apr-Jul	10-30 cm
MIEF	*Milium effusum*	woodland millet grass	N	G	M		P	May -Jul	45-180 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
MIRI	*Mimulus ringens*	blue monkey flower	N	H	D		P	Jun-Sep	30-100 cm
MIAL4	*Mirabilis albida*	hairy four o'clock	N	H	D		P	Jun-Oct	30-100 cm
MINY	*Mirabilis nyctaginea*	heart-leaved four o'clock	N	H	D		P	May-Sep	60-120 cm
MIDI3	*Mitella diphylla*	two-leaved miterwort	N	H	D	CTs33; MHs39	P	Apr-Jun	25-45 cm
MOLA6	*Moehringia lateriflora*	side-flowering sandwort	N	H	D		P	Mar-Jun	5-30 cm
MOVE	*Mollugo verticillata*	carpetweed	I	H	D		A	Jun-Sep	2-15 cm
MOFI	*Monarda fistulosa*	wild bergamot	N	H	D	UPs13; UPs23	P	Jun-Aug	60-120 cm
MOAL	*Morus alba*	white mulberry	I	D	D		P	Mar-Apr	10-20 m
MUCU3	*Muhlenbergia cuspidata*	Plains muhly	N	G	M	CTs12; UPs13	P	May-Jun	20-40 cm
MUFR2	*Muhlenbergia frondosa*	swamp muhly grass	N	G	M		P	Mar-May	30-90 cm
MUGL3	*Muhlenbergia glomerata*	clustered muhly grass	N	G	M	OOp93; WMs83	P	May-Jun	30-120 cm
MUME2	*Muhlenbergia mexicana*	Mexican muhly grass	N	G	M		P	Jul-Sep	30-90 cm
MURA	*Muhlenbergia racemosa*	marsh muhly grass	N	G	M		P	Aug-Sep	25-60 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
MUSC	*Muhlenbergia schreberi*	dropseed muhly grass WL	N	G	M		P	Sep-Oct	10-30 cm
MUPU3	*Mulgedium pulchellum*	beautiful blue lettuce	N	H	D		B/P	Jun-Sep	30-100 cm
MYAQ	*Myosoton aquaticum*	giant chickweed	I	H	D		P	Jun-Sep	20-50 cm
MYSI	*Myriophyllum sibiricum*	northern water milfoil	N	H; S	D		P	Jun-Sep	70-90 cm
NAFL	*Najas flexilis*	flexuous naiad	N	H; S	M	MRp93	A	Aug-Sep	30-75 cm
NECA2	*Nepeta cataria*	catnip	I	H	D		P	Jul-Oct	30-120 cm
NULUV	*Nuphar variegata*	bullhead pond-lily	N	F; H	D		P	Jun-Aug	200 cm
OEBI	*Oenothera biennis*	common evening primrose	N	H	D		B	Jul-Oct	60-180 cm
ONSE	*Onoclea sensibilis*	sensitive fern	N	H	F	WMs83	P	Jun-Aug	30-75 cm
ONMO	*Onosmodium molle*	false gromwell	N	H	D	UPs13	P	Jun-Jul	60-100 cm
OPMA2	*Opuntia macrorhiza*	devil's tongue SC	N	K	D		P	May-Jun	30-100 cm
OSCL	*Osmorhiza claytonii*	Clayton's sweet cicely	N	H	D	FFs59; MHs38; MHs39; MHs49	P	May-Jul	25-70 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
OSLO	*Osmorhiza longistylis*	aniseroot	N	H	D	FFs59; MHs49	P	Jun-Jul	80-120 cm
OSVI	*Ostrya virginiana*	ironwood	N	D	D	MHs38; MHs39; MHs49	P	May	6-14 m
OXDI2	*Oxalis dillenii*	southern wood sorrel	N	H	D		P	Jun-Oct	15-40 cm
OXVI	*Oxalis violacea*	violet wood sorrel	N	H	D		P	Apr-Jun	10-20 cm
PAPA20	*Packera paupercula*	balsam ragwort	N	H	D	UPs13	P	May-Jun	20-45 cm
PAPL12	*Packera plattensis*	prairie ragwort	N	H	D	UPs13	B/P	Apr-Jun	20-60 cm
PAPS5	*Packera pseudaurea*	falsefold groundsel	N	H	D		P	Jul-Aug	50-70 cm
PAQU	*Panax quinquefolius*	American ginseng SC	N	H	D		P	Jul-Aug	20-50 cm
PACA6	*Panicum capillare*	witch grass	N	G	M		A	Jul-Sep	20-80 cm
PADI	*Panicum dichotomiflorum*	fall panic grass	N	G	M	UPs14	A	Jul-Sep	1-2 m
PAVI2	*Panicum virgatum*	switchgrass	N	G	M	UPs14; UPs23; WPs54	P	Jul-Sep	60-300 cm
PAPES5	*Parietaria pensylvanica*	pellitory	N	H	D		A	May-Sep	15-45 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
PAQU2	*Parthenocissus quinquefolia*	Virginia creeper	N	C	D	CTs33; FFs59; FFs68; MHs38; MHs39; MHs49; UPs14; UPs24	P	May -Jun	3-10 m
PAVI5	*Parthenocissus vitacea*	woodbine	N	C	D	UPs14	P	May -Jul	1-30 cm
PASM	*Pascopyrum smithii*	western wheatgrass	N	G	M		P	Jun-Jul	60 cm
PASA2	*Pastinaca sativa*	wild parsnip	I	H	D		B/P	Jul-Aug	1-1.6 m
PECA	*Pedicularis canadensis*	wood betony	N	H	D	UPs23	P	May -Jun	10-40 cm
PELA2	*Pedicularis lanceolata*	swamp lousewort	N	H	D	OOp93; WMs83; WPs54	P	Aug -Sep	30-100 cm
PEAR6	*Pediomelum argophyllum*	silverleaf scurfpea	N	H	D	UPs23; UPs24	P	Jun-Aug	30-100 cm
PEES	*Pediomelum esculentum*	prairie turnip	N	H	D	UPs13; UPs23	P	May -Jul	30-40 cm
PEGL	*Pellaea glabella*	smooth cliffbrake	N	H	F	CTs33	P	Jun-Aug	1-40 cm
PESE6	*Penthorum sedoides*	ditch stonecrop	N	H	D		P	Mar - May	30-70 cm
PESE7	*Peritoma serrulata*	spider-flower	N	H	D		A	May -Jun	30-80 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
PEAM8	*Persicaria amphibia*	water smartweed	N	F; H	D	MRp83; MRp93; WMs83; WMs92	P	Jun-Sep	30-100 cm
PEHY6	*Persicaria hydropiper*	marsh waterpepper	I	H	D		A	Jul-Sep	20-75 cm
PELA22	*Persicaria lapathifolia*	nodding smartweed	N	H	D		A	Jul-Sep	60-180 cm
PEMA24	*Persicaria maculosa*	lady's thumb	I	H	D	MRp83	A/P	Jun-Sep	30-75 cm
PEPE19	*Persicaria pensylvanica*	Pennsylvania smartweed	N	H	D		A	Jun-Sep	45-90 cm
PEPU18	*Persicaria punctata*	dotted smartweed	N	H	D	MRp93	A/P	Jul-Sep	30-75 cm
POSA5	*Persicaria sagittata*	arrow-leaved tearthumb	N	H	D	MRp93	A/P	Jun-Oct	45-60 cm
POVI2	*Persicaria virginiana*	Virginia knotweed	N	H	D	FFs59; FFs68	A/P	Jul-Sep	30-120 cm
PHAR3	*Phalaris arundinacea*	reed canary grass	N	G	M		P	Apr-Jun	60-150 cm
PHPA29	*Phemeranthus parviflorus*	small-flowered fameflower	N	H	D	ROs12	P	Jun-Jul	7-15 cm
PHPR3	*Phleum pratense*	timothy	I	G	M		P	Jun-Aug	30-100 cm
PHDI5	*Phlox divaricata*	blue phlox	N	H	D	FFs59; MHs39; MHs49	P	Apr-Jun	25-45 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
PHPIF	*Phlox pilosa*	prairie phlox	N	H	D	UPs23; UPs24; WPs54	P	May -Jul	15-60 cm
PHAU7	*Phragmites australis*	common reedgrass	I/N	G	M	MRp83; WMs92	P	Jun-Aug	1-2 m
PHLE5	*Phryma leptostachya*	lopseed	N	H	D	MHs38; MHs39	P	Jul-Sep	30-100 cm
PHLA3	*Phyla lanceolata*	fogfruit	N	H	D		P	Jun-Sep	15-50 cm
PHHE5	*Physalis heterophylla*	clammy ground cherry	N	H	D		P	Jun-Sep	30-60 cm
PHVI5	*Physalis virginiana*	Virginia ground cherry	N	H	D	UPs13; UPs14; UPs23	P	Jun-Aug	30-100 cm
PHOP	*Physocarpus opulifolius*	ninebark	N	D	D		P	May -Jul	2-3 m
PHVI8	*Physostegia virginiana*	obedient plant	N	H	D		P	Aug - Nov	1-2 m
PIFO	*Pilea fontana*	black-fruited clearweed	N	H	D	FFs59; FFs68; MRp83; WMs83	A	Jul-Sep	10-50 cm
PIPU2	*Pilea pumila*	dwarf clearweed	N	H	D	FFs59; FFs68; MRp83; WMs83	A	Jul-Sep	10-50 cm
PIRA5	*Piptatherum racemosum*	black-fruited rice grass	N	G	M		P	Aug	30-90 cm
PLMA2	*Plantago major*	common plantain	I	H	D		P	Aug - Nov	1-2 m
PLPA2	*Plantago patagonica*	Pursh's plantain	N	H	D	ROs12	A	Mar -Jun	1-30 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
PLRU	*Plantago rugelii*	Rugel's plantain	N	H	D		P	May -Oct	10-60 cm
PLAQ2	*Platanthera aquilonis*	northern green orchid	N	H	M		P	May - Aug	10-60 cm
POAN	*Poa annua*	annual bluegrass	I	G	M		P	Jan-Dec	3-30 cm
POCO	*Poa compressa*	Canada bluegrass	I	G	M		P	Jun-Jul	10-50 cm
POPR	*Poa pratensis*	Kentucky bluegrass	I/N	G	M		P	May - Aug	30-100 cm
PODO3	*Polanisia dodecandra*	clammy weed	N	H	D		A	Jul-Sep	30-60 cm
POSA3	*Polygala sanguinea*	blood milkwort	N	H	D		A	Jul-Sep	10-30 cm
POSE3	*Polygala senega*	Seneca snakeroot	N	H	D		P	May -Jul	25-45 cm
POBI2	*Polygonatum biflorum*	giant Solomon's seal	N	H	M		P	May -Jul	30-100 cm
PORA3	*Polygonum ramosissimum*	bushy knotweed	N	H	D		A	Jun-Oct	1-2 m
POTE2	*Polygonum tenue*	slender knotweed	N	H	D	ROs12	A	Jun-Oct	10-50 cm
POCA11	*Polymnia canadensis*	leafcup	N	H	D		P	May - Aug	50-150 cm
POVI7	*Polypodium virginianum*	common polypody	N	H	F	CTs33	P	Jun-Aug	10-25 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
PODE3	*Populus deltoides*	cottonwood	N	D	D	FFs59; FFs68	P	Mar -Apr	30-55 m
POTR5	*Populus tremuloides*	quaking aspen	N	D	D		P	Mar -Jun	12-35 m
POOL	*Portulaca oleracea*	purslane	I/N	H	D		A	Jun-Sep	30-60 cm
POAM5	*Potamogeton amplifolius*	large-leaved pondweed	N	H; S; F	M		P	Jun-Aug	6-100 cm
POCR3	*Potamogeton crispus*	curly pondweed	I	F; H	M		P	May -Jun	30-80 cm
PONA4	*Potamogeton natans*	floating pondweed	N	H; S; F	M		P	Jul	5-10 cm
PONO2	*Potamogeton nodosus*	American pondweed	N	F; H	M		P	May - Aug	30-100 cm
POPR5	*Potamogeton praelongus*	white-stemmed pondweed	N	F; H	M		P	Apr-May	3 m
PORI2	*Potamogeton richardsonii*	Richardson's pondweed	N	F; H	M	MRp93	P	Jun-Oct	1 m
POZO	*Potamogeton zosteriformis*	flat-stemmed pondweed	N	F; H	M	MRp83	P	Jul	1-1.5 m
POAR8	*Potentilla argentea*	silvery cinquefoil	I	H	D		P	May -Jul	30-40 cm
POAR7	*Potentilla arguta*	tall cinquefoil	N	H	D	UPs13; UPs14; UPs23	P	Jul	50-90 cm
PONO3	*Potentilla norvegica*	rough cinquefoil	N	H	D		A/B/P	Jun-Aug	30-100 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
COPA28	*Potentilla palustris*	marsh cinquefoil	N	H	D		P	Jun-Aug	30-60 cm
POPA15	*Potentilla paradoxa*	bushy cinquefoil WL	N	H	D		A/B/P	Jun-Aug	20-30 cm
PORE5	*Potentilla recta*	rough-fruited cinquefoil	I	H	D		P	Jun-Aug	30-75 cm
POSI	*Potentilla simplex*	oldfield cinquefoil	N	H	D		P	May-Jul	15-60 cm
PRAL2	*Prenanthes alba*	white rattlesnakeroot	N	H	D		B/P	Aug-Sep	30-150 cm
PRRA	*Prenanthes racemosa*	smooth rattlesnakeroot	N	H	D	UPs23	P	Aug-Oct	30-150 cm
PRVU	*Prunella vulgaris*	heal-all	N	H	D		P	Jun-Oct	15-50 cm
PRAM	*Prunus americana*	wild plum	N	D	D	UPs24	P	May	3-8 m
PRPE2	*Prunus pensylvanica*	pin cherry	N	D	D		P	May-Jun	6-10 m
PRSE2	*Prunus serotina*	black cherry	N	D	D	MHs38	P	May-Jun	15-30 m
PRVI	*Prunus virginiana*	chokecherry	N	D	D	FFs59; MHs38; MHs39; MHs49; UPs14; UPs24	P	May-Jun	6-10 m
PSOB3	*Pseudognaphalium obtusifolium*	sweet everlasting	N	H	D		A/B	Jul-Sep	30-100 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
PYVI	*Pycnanthemum virginianum*	Virginia mountain mint	N	H	D	UPs23; WMs83; WPs54	P	Jul-Sep	10-100 cm
QUEL	*Quercus ellipsoidalis*	northern pin oak	N	D	D	UPs14; UPs24	P	Mar - May	10-20 m
QUMA2	*Quercus macrocarpa*	bur oak	N	D	D	MHs38; MHs49; ROs12; UPs14; UPs24	P	Mar	8-15 m
QURU	*Quercus rubra*	northern red oak	N	D	D	MHs38; MHs39; ROs12	P	May	11-25 m
RAAB	*Ranunculus abortivus*	kidney-leaved buttercup	N	H	D	MHs39	B/P	Mar - May	10-60 cm
RAAQ	*Ranunculus aquatilis*	white water crowfoot	N	H; S	D		P	Apr-Aug	20-80 cm
RACY	*Ranunculus cymbalaria*	seaside crowfoot	N	H	D		P	May - Aug	5-20 cm
RAFA	*Ranunculus fascicularis*	early buttercup	N	H	D		P	Jan-Jun	10-15 cm
RAFL	*Ranunculus flabellaris*	large yellow water crowfoot	N	H	D	WMs92	P	Jun-Jul	40-60 cm
RAFL2	*Ranunculus flammula*	creeping spearwort	N	H; S	D		P	Jun-Sep	10-45 cm
RAGM	*Ranunculus gmelinii*	small yellow water crowfoot	N	H; S	D		P	May -Sep	1-10 cm
RAHI	*Ranunculus hispidus*	hispid buttercup	N	H	D	FFs59; MHs49	P	Apr-Jun	15-45 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
RAPE2	*Ranunculus pensylvanicus*	bristly buttercup	N	H	D	WMs92	A/P	Jul-Aug	60-100 cm
RARE2	*Ranunculus recurvatus*	hooked crowfoot	N	H	D		P	Apr-Jun	15-30 cm
RARH	*Ranunculus rhomboideus*	prairie buttercup	N	H	D		P	Apr-Jun	5-22 cm
RASC3	*Ranunculus sceleratus*	cursed crowfoot	N	H	D	MRp83	A/P	Jun-Oct	10-75 cm
RAPI	*Ratibida pinnata*	gray-headed coneflower	N	H	D	UPs23; UPs24; WPs54	P	May-Aug	80-120 cm
RHCA3	*Rhamnus cathartica*	common buckthorn	I	D	D		P	Jun-Jul	6 m
RHGL	*Rhus glabra*	smooth sumac	N	D	D	ROs12; UPs13; UPs14; UPs24	P	Jul-Aug	4 m
RHTY	*Rhus hirta*	staghorn sumac	N	D	D		P	Jun-Jul	1-2 m
RHCA11	*Rhynchospora capillacea*	hair-like beak rush T	N	G	M	OOp93	P	Jun-Oct	10-40 cm
RIAM2	*Ribes americanum*	wild black currant	N	D	D		P	May-Jun	60-150 cm
RICY	*Ribes cynosbati*	prickly gooseberry	N	D	D	FFs59; MHs38; MHs39; MHs49	P	Apr-Jun	60-120 cm
RIMI	*Ribes missouriense*	Missouri gooseberry	N	D	D	FFs59; MHs38; MHs39; MHs49	P	Apr-Jun	1-2 m

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
ROPS	*Robinia pseudoacacia*	black locust	N	D	D		P	May-Jun	20-25 m
ROPA2	*Rorippa palustris*	Icelandic yellow cress	N	H	D		A/B/P	Mar-Sep	10-100 cm
ROAR3	*Rosa arkansana*	prairie rose	N	D	D	UPs13; UPs14; UPs23; UPs24; WPs54	P	Jun-Jul	50-60 cm
ROBL	*Rosa blanda*	smooth wild rose	N	D	D		P	Jun-Jul	1-2 m
RUAL	*Rubus allegheniensis s.s.*	Allegheny blackberry	N	D	D	ROs12	P	May-Jun	1-2 m
RUID	*Rubus idaeus*	red raspberry	I/N	D	D	ROs12	P	May-Aug	1-4 m
RUOC	*Rubus occidentalis*	black raspberry	N	D	D	ROs12	P	May-Jun	1.5-2 m
RUPU	*Rubus pubescens*	dwarf raspberry	N	H	D	OOp93; ROs12; WMs83	P	May-Jun	10-30 cm
RUHI2	*Rudbeckia hirta*	black-eyed susan	N	H	D		A/B/P	Jun-Oct	30-100 cm
RULA3	*Rudbeckia laciniata*	tall coneflower	N	H	D	FFs59; FFs68; MHs49	P	Jul-Sep	50-300 cm
RUAC3	*Rumex acetosella*	common sheep sorrel	I	H	D	ROs12	P	Mar-Nov	45 cm
RUAL4	*Rumex altissimus*	tall water dock	N	H	D		P	May-Aug	1 m

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
RUBR14	*Rumex britannica*	great water dock	N	H	D	MRp83; MRp93; WMs83; WMs92	P	Jun-Aug	1-2 m
RUCR	*Rumex crispus*	curly dock	I	H	D		P	Jun-Jul	30-150 cm
RUMA4	*Rumex fueginus*	golden dock	N	H	D	MRp93; WMs92	A/B	Apr-Aug	40-90 cm
RUPA5	*Rumex patientia*	patience dock	I	H	D		P	May-Aug	40-100 cm
RUVE3	*Rumex verticillatus*	whorled water dock	N	H	D		P	Apr-May	1-1.5 m
SACA21	*Sagittaria calycina*	hooded arrowhead	N	H	M		P	Jul-Sep	80-100 cm
SALA2	*Sagittaria latifolia*	broad-leaved arrowhead	N	H	M	MRp83; MRp93	P	Aug-Sep	45-90 cm
SARI	*Sagittaria rigida*	sessile-fruited arrowhead	N	H	M	MRp93	P	Jul-Sep	15-75 cm
SAAM2	*Salix amygdaloides*	peach-leaved willow	N	D	D		P	Apr-May	10-22 m
SABE2	*Salix bebbiana*	Bebb's willow	N	D	D	WMs83	P	Apr-May	3-10 m
SADI	*Salix discolor*	pussy willow	N	D	D	OOp93; WMs83; WMs92; WPs54	P	Feb-Mar	3-10 m
SAER	*Salix eriocephala s.s.*	heart-leaved willow	N	D	D	WMs83	P	Feb-Mar	3-10 m

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
SALU2	*Salix famelica*	hungry willow	N	D	D		P	Apr-Jun	10 m
SAIN3	*Salix interior*	sandbar willow	N	D	D		P	Apr-May	50-500 cm
SANI	*Salix nigra*	black willow	N	D	D	FFs68	P	Apr-May	5-25 m
SAPE2	*Salix pedicellaris*	bog willow	N	D	D		P	Apr-Jul	20-150 cm
SAPE5	*Salix petiolaris*	slender willow	N	D	D	WMs83; WMs92	P	Apr-Jun	1-6 m
SATR12	*Salsola tragus*	Russian thistle	I	H	D		A	Jul-Oct	1 m
SARE3	*Salvia reflexa*	lance-leaved sage	N	H	D		A	Jul-Aug	30-60 cm
SACA12	*Sambucus canadensis*	common elder	N	D	D	FFs59	P	May-Jun	2-4 m
SARA2	*Sambucus racemosa*	red elderberry	N	D	D	CTs33; MHs39; MHs49	P	Jul-Aug	3-5 m
SACA13	*Sanguinaria canadensis*	bloodroot	N	H	D	MHs38; MHs39; MHs49	P	Mar-May	15-30 cm
SACA15	*Sanicula canadensis*	Canadian black snakeroot	N	H	D		B	Jun-Jul	30-120 cm
SAGR6	*Sanicula gregaria*	gregarious black snakeroot	N	H	D	FFs59; MHs39	P	Jun-Jul	30-100 cm
SAMA2	*Sanicula marilandica*	maryland black snakeroot	N	H	D	FFs59; MHs38	P	May-Jul	90-120 cm
SAOF4	*Saponaria officinalis*	bouncing bet	I	H	D		P	Jun-Sep	30-80 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
SCSC	*Schizachyrium scoparium*	little bluestem	N	G	M	UPs14; UPs23; UPs24	P	Apr-May	30-100 cm
SCHE5	*Schoenoplectus heterochaetus*	slender bulrush WL	N	G	M	MRp83; MRp93	P	May - Aug	1-2.5 m
SCPU10	*Schoenoplectus pungens*	three-square bulrush	N	G	M		P	Jun-Aug	1-1.5 m
SCSM3	*Schoenoplectus smithii*	blunt-scale bulrush	N	G	M		A	Jul-Sep	2-50 cm
SCTA2	*Schoenoplectus tabernaemontani*	soft stem bulrush	N	G	M	MRp83; MRp93; WMs92	P	Apr-May	1-2 m
SCAT2	*Scirpus atrovirens*	dark green bulrush	N	G	M	WMs83	P	May - Aug	1-2 m
SCCY	*Scirpus cyperinus s.s.*	woolgrass	N	G	M		P	Jun-Sep	1-2 m
SCPA8	*Scirpus pallidus*	pale bulrush	N	G	M	WMs83	P	Jul-Sep	2 m
SCVE2	*Scleria verticillata*	whorled nutrush T	N	G	M		A	Jun-Oct	10-60 cm
SCFE	*Scolochloa festucacea*	whitetop	N	G	M	MRp83; MRp93; WMs92	P	Jun-Jul	1-1.5 m
SCLA	*Scrophularia lanceolata*	lance-leaved figwort	N	H	D		P	May -Jul	60-200 cm
SCMA2	*Scrophularia marilandica*	Maryland figwort	N	H	D		P	Jul-Oct	60-300 cm
SCGA	*Scutellaria galericulata*	marsh skullcap	N	H	D	MRp83; MRp93; WMs83; WMs92	P	Jun-Sep	30-75 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
SCLA2	*Scutellaria lateriflora*	mad dog skullcap	N	H	D	FFs68; MRp93	P	Jun-Oct	25-75 cm
SCPAM	*Scutellaria leonardii*	Leonard's skullcap	N	H	D		P	May-Jul	10-20 cm
SCPA7	*Scutellaria parvula*	prairie skullcap	N	H	D		P	Mar-Jun	1-30 cm
SEIN2	*Senecio integerrimus*	lambstongue ragwort	N	H	D		B/P	Apr-May	20-70 cm
SEFA	*Setaria faberi*	giant foxtail	I	G	M		A	Jul-Sep	60-130 cm
SEPU8	*Setaria pumila*	yellow foxtail	I	G	M		A	Jul-Oct	5-130 cm
SEVE3	*Setaria verticillata*	bristly foxtail	I	G	M		A	Jun-Sep	10-100 cm
SEVI4	*Setaria viridis*	green foxtail	I	G	M		A	Sep-Oct	30-60 cm
SIAN	*Sicyos angulatus*	bur cucumber	N	H	D	FFs68	A	Aug-Sep	1.5-6 m
SIAN2	*Silene antirrhina*	sleepy catchfly	N	H	D	ROs12	A	Apr-Aug	60-80 cm
SICS	*Silene csereii*	smooth catchfly	I	H	D		B/P	Jun-Aug	35-65 cm
SILA21	*Silene latifolia*	white campion	I	H	D		B/P	Jun-Sep	80-100 cm
SIST	*Silene stellata*	starry campion	N	H	D		P	Jun-Aug	30-80 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
SILA3	*Silphium laciniatum*	compass plant	N	H	D		P	Jul-Sep	1-3 m
SIPE2	*Silphium perfoliatum*	cup plant	N	H	D	WPs54	P	Jul-Sep	75-250 cm
SICA9	*Sisyrinchium campestre*	field blue-eyed grass	N	H	M	UPs13	P	Apr-Jun	30-40 cm
SIMU3	*Sisyrinchium mucronatum*	pointed-petal blue-eyed grass	N	H	M		P	May-Jun	35-45 cm
SISU2	*Sium suave*	water parsnip	N	H	D	MRp83; MRp93; WMs92	P	Jul-Aug	60-120 cm
SMEC	*Smilax ecirrhata*	erect carrion flower	N	H	M	FFs59; FFs68; MHs38; MHs39; MHs49; UPs14	P	May-Jun	30-100 cm
SMIL	*Smilax illinoensis*	Illinois carrion flower	N	H	M	FFs59; FFs68; MHs38; MHs49; UPs14	P	May-Jun	30-100 cm
SMLA3	*Smilax lasioneura*	common carrion flower	N	H	M	MHs38; MHs49	P	May-Jun	250 cm
SMTA2	*Smilax tamnoides*	greenbrier	N	C	M	FFs59; FFs68	P	May-Jun	3-6 m
SODU	*Solanum dulcamara*	bittersweet nightshade	I	C; H	D		P	Jun-Sep	60-250 cm
SONI	*Solanum nigrum*	black nightshade	I	H	D		A/P	Mar-Oct	30 cm
SORO	*Solanum rostratum*	buffalo bur	N	H	D		A	Jun-Sep	30-100 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
SOAL6	*Solidago altissima*	late goldenrod	N	H	D		P	Aug -Oct	50-200 cm
SOGI	*Solidago gigantea*	giant goldenrod	N	H	D	OOp93; WMs83; WMs92; WPs54	P	Aug -Sep	50-200 cm
SONE	*Solidago nemoralis*	gray goldenrod	N	H	D	ROs12; UPs13; UPs14; UPs23; UPs24	P	Aug -Oct	20-100 cm
SOPT4	*Solidago ptarmicoides*	upland white aster	N	H	D		P	Jul-Oct	10-40 cm
SORI2	*Solidago rigida*	stiff goldenrod	N	H	D	UPs13; UPs23; UPs24; WPs54	P	Aug -Oct	60-150 cm
SOSP2	*Solidago speciosa*	showy goldenrod	N	H	D	UPs14	P	Sep-Oct	50-200 cm
SOOL	*Sonchus oleraceus*	common sow thistle	I	H	D		A	Jun-Oct	10-140 cm
SONU2	*Sorghastrum nutans*	Indian grass	N	G	M	ROs12; UPs13; UPs14; UPs23; UPs24; WPs54	P	May -Jun	50-200 cm
SPEU	*Sparganium eurycarpum*	giant bur-reed	N	H	M	MRp83; MRp93; WMs92	P	Jun-Aug	120 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
SPPE	*Spartina pectinata*	prairie cordgrass	N	G	M	MRp93; UPs23; WMs83; WMs92; WPs54	P	Sep-Oct	1-2.5 m
SPIN3	*Sphenopholis intermedia*	slender wedge grass	N	G	M		P	May	30-120 cm
SPAL2	*Spiraea alba*	white meadowsweet	N	D	D		P	May	50-100 cm
SPPO	*Spirodela polyrrhiza*	greater duckweed	N	F; H	M	MRp83; MRp93	P	Jun-Sep	15 cm
SPCO16	*Sporobolus compositus*	composite dropseed	N	G	M		P	Aug-Oct	60-170 cm
SPCR	*Sporobolus cryptandrus*	sand dropseed	N	G	M		P	Aug-Sep	35-120 cm
SPHE	*Sporobolus heterolepis*	prairie dropseed	N	G	M	ROs12;UPs13; UPs14; UPs23; UPs24; WPs54	P	Jun-Sep	30-70 cm
SPNE2	*Sporobolus neglectus*	annual dropseed	N	G	M		A	Aug-Sep	10-40 cm
STTE	*Stachys hispida*	smooth hedge nettle	N	H	D		P	Jun-Aug	30-120 cm
STPA	*Stachys palustris*	woundwort	N	H	D	FFs68; MRp83; MRp93; WMs83; WMs92	P	Jun-Aug	30-100 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
STTR	*Staphylea trifolia*	bladdernut	N	D	D		P	Apr-May	3-11 m
STLO	*Stellaria longifolia*	long-leaved chickweed	N	H	D		P	May-Jul	10-35 cm
STME2	*Stellaria media*	common chickweed	I	H	D		A/P	Mar-Oct	5-40 cm
STHE9	*Strophostyles helvola*	wild bean	N	H	D		A	Jul-Oct	60-250 cm
STLE6	*Strophostyles leiosperma*	trailing pea	N	H	D		A	Aug-Sep	30-75 cm
STPE15	*Stuckenia pectinata*	sago pondweed	N	H; S	M	MRp93	P	Sep	10 cm
SYOC	*Symphoricarpos occidentalis*	wolfberry	N	D	D	UPs13; UPs23; UPs24	P	Jun-Jul	90 cm
SYBO2	*Symphyotrichum boreale*	bog aster	N	H	D	OOp93; WMs83; WMs92	P	Aug-Oct	13-85 cm
SYCI2	*Symphyotrichum ciliatum*	short-rayed aster	N	H	D		A	Aug-Oct	7-70 cm
SYCO4	*Symphyotrichum cordifolium*	heart-leaved aster	N	H	D		P	Aug-Oct	20-120 cm
SYDR	*Symphyotrichum drummondii*	Drummond's aster	N	H	D		P	Sep-Oct	60-120 cm
SYER	*Symphyotrichum ericoides*	heath aster	N	H	D	UPs13; UPs14; UPs23; WPs54	P	Aug-Oct	30-100 cm
SYFA	*Symphyotrichum falcatum*	white prairie aster	N	H	D		P	Jun-Oct	10-80 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
SYLA3	*Symphyotrichum laeve*	smooth blue aster	N	H	D	UPs23; UPs24	P	Aug-Oct	30-100 cm
SYLA6	*Symphyotrichum lanceolatum*	panicled aster	N	H	D	FFs68; WMs83; WMs92	P	Jul-Oct	30-150 cm
SYNO2	*Symphyotrichum novae-angliae*	New England aster	N	H	D	OOp93; WPs54	P	Oct-Nov	1-1.5 m
SYOB	*Symphyotrichum oblongifolium*	aromatic aster	N	H	D	UPs13	P	Sep-Oct	30-60 cm
SYPU	*Symphyotrichum puniceum*	purplestem aster	N	H	D		P	Aug-Oct	30-200 cm
SYSE2	*Symphyotrichum sericeum*	silky aster	N	H	D	UPs13; UPs23	P	Aug-Oct	30-60 cm
TALA2	*Taraxacum erythrospermum*	red-seeded dandelion	I	H	D		P	Jun-Oct	5-30 cm
TAOF	*Taraxacum officinale*	common dandelion	I/N	H	D		P	Jan-Dec	30-100 cm
TEPA5	*Tephroseris palustris*	swamp ragwort	N	H	D		A/B	May-Jul	30-150 cm
TECA3	*Teucrium canadense*	germander	N	H	D	FFs68; MRp83; MRp93; WMs92	P	Jul-Aug	30-120 cm
THDA	*Thalictrum dasycarpum*	tall meadow-rue	N	H	D	OOp93; UPs23; UPs24; WMs83; WPs54	P	May-Jul	40-150 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
THDI	*Thalictrum dioicum*	early meadow-rue	N	H	D	FFs59; MHs38	P	Apr-Jun	30-80 cm
THBA	*Thaspium barbinode*	hairy-jointed meadow-parsnip SC	N	H	D		P	May-Jun	60-100 cm
THPA	*Thelypteris palustris*	eastern marsh fern	N	H	F	MRp83; WMs83	P	Jun-Aug	15-75 cm
THAR5	*Thlaspi arvense*	pennycress	I	H	D		A	Apr-May	15-55 cm
TIAM	*Tilia americana*	basswood	N	D	D	CTs33; FFs59; MHs38; MHs39; MHs49	P	Apr-Jul	30-40 m
TORY	*Toxicodendron rydbergii*	western poison ivy	N	D	D	CTs12; CTs33; FFs59; FFs68; MHs38; UPs24	P	Jun-Jul	30-100 cm
TRBR	*Tradescantia bracteata*	bracted spiderwort	N	H	M		P	Jun-Aug	5-30 cm
TRDU	*Tragopogon dubius*	yellow goat's beard	I	H	D		A/B	May-Sep	30-100 cm
TRFR	*Triadenum fraseri*	marsh St. John's wort	N	H	D		P	Jul-Aug	30-60 cm
TRCA5	*Trifolium campestre*	field hop clover	I	H	D		A/B	May-Sep	15-25 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
TRHY	*Trifolium hybridum*	alsike clover	I	H	D		A/P	Jun-Sep	30-60 cm
TRPR2	*Trifolium pratense*	red clover	I	H	D		B/P	Jun-Sep	15-100 cm
TRRE3	*Trifolium repens*	white clover	I	H	D		P	May -Oct	7-15 cm
TRMA 20	*Triglochin maritima*	seaside arrowgrass	N	H	M	OOp93	P	Jun-Aug	5-15 cm
TRPA2 8	*Triglochin palustris*	marsh arrowgrass	N	H	M	OOp93	P	Jun-Aug	10-45 cm
TRCE	*Trillium cernuum*	nodding trillium	N	H	M	MHs39	P	May -Jun	20-50 cm
TRFL6	*Trillium flexipes*	drooping trillium	N	H	M	MHs39; MHs49	P	May -Jun	20-50 cm
TRNI2	*Trillium nivale*	snow trillium SC	N	H	M		P	Mar - May	7-15 cm
TRPE4	*Triodanis perfoliata*	clasping-leaved Venus' looking-glass	N	H	D		A	Apr-May	30-100 cm
TRPE5	*Triosteum perfoliatum*	late horse gentian	N	H	D		P	May -Jul	60-90 cm
TYLA	*Typha latifolia*	broad-leaved cattail	N	H	M	MRp83; OOp93; WMs83	P	May -Jul	1-3 m

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
ULAM	*Ulmus americana*	American elm	N	D	D	FFs59; FFs68; MHs38; MHs39; MHs49	P	Feb-Apr	20-30 m
ULPU	*Ulmus pumila*	Siberian elm	I	D	D		P	Mar-Apr	15-20 m
ULRU	*Ulmus rubra*	red elm	N	D	D	FFs59; FFs68; MHs38; MHs39; MHs49	P	Jan-Dec	10-22 m
ULTH	*Ulmus thomasii*	rock elm	N	D	D	MHs49	P	Mar-Apr	20-30 m
URDI	*Urtica dioica*	stinging nettle	I/N	H	D	FFs59; FFs68; MHs49; WMs92	P	Jun-Sep	1-3 m
UTMA	*Utricularia vulgaris*	common bladderwort	N	H; S	D	MRp83; MRp93	P	Jun-Aug	30-100 cm
UVGR	*Uvularia grandiflora*	large-flowered bellwort	N	H	M	MHs38; MHs39; MHs49	P	Apr-Jun	30-60 cm
VAHI2	*Vaccaria hispanica*	cowherb	I	H	D		A	Jun-Aug	20-100 cm
VAMA	*Vaccinium macrocarpon*	large cranberry	N	B	D		P	Jun-Aug	5-15 cm
VETH	*Verbascum thapsus*	common mullein	I	H	D		B	Jun-Sep	60-200 cm
VEBR	*Verbena bracteata*	large-bracted vervain	N	H	D		A/B/P	May-Oct	1-30 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
VEHA2	*Verbena hastata*	blue vervain	N	H	D	WMs83	B/P	Jun-Sep	30-200 cm
VEST	*Verbena stricta*	hoary vervain	N	H	D	UPs13	A/P	Jun-Sep	30-100 cm
VEUR	*Verbena urticifolia*	white vervain	N	H	D		P	Jul-Sep	1-1.5 m
VEFA2	*Vernonia fasciculata*	bunched ironweed	N	H	D		P	Jul-Sep	1-2 m
VEAN2	*Veronica catenata*	water speedwell	N	H	D		B/P	May-Sep	30-100 cm
VEPE2	*Veronica peregrina*	purslane speedwell	N	H	D		A	May-Oct	7-30 cm
VEVI4	*Veronicastrum virginicum*	Culver's root	N	H	D	WPs54	P	Jun-Aug	1-2 m
VILE	*Viburnum lentago*	nannyberry	N	D	D	FFs59; MHs38; MHs49	P	May	3-11 m
VIRA	*Viburnum rafinesquianum*	downy arrowwood	N	D	D	MHs38	P	May-Jun	2-4 m
VIOPA2	*Viburnum trilobum*	highbush cranberry	N	D	D	CTs33	P	May-Jul	1.5-4 m
VIAM	*Vicia americana*	American vetch	N	H	D	UPs23	P	May-Jul	30-100 cm
VISAN2	*Vicia angustifolia*	narrow-leaved vetch	I	H	D		A	May-Sep	75 cm
VIVI	*Vicia villosa*	hairy vetch	I	H	D		A/B/P	Jun-Aug	30-100 cm

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
VIBL	*Viola blanda*	big-leaved white violet	N	H	D	FFs59; FFs68; MHs39; MHs49	P	Apr-Jun	7-15 cm
VICA4	*Viola canadensis*	canadian white violet	N	H	D	FFs59; FFs68; MHs39; MHs49	P	Apr-Jul	20-40 cm
VIMA2	*Viola macloskeyi*	small white violet	N	H	D	FFs59; FFs68; MHs39; MHs49	P	May-Aug	1-30 cm
VINE	*Viola nephrophylla*	northern bog violet	N	H	D	FFs59; FFs68; OOp93; WMs83; WPs54	A/P	May-Jun	10-25 cm
VIPA3	*Viola palmata*	bearded birdfoot violet	N	H	D	FFs59; FFs68; MHs49; UPs14; UPs13; UPs23	P	Apr-Jun	7-15 cm
VIPU3	*Viola pubescens*	yellow violet	N	H	D	FFs59; FFs68; MHs38; MHs39; MHs49	P	Apr-Jun	10-45 cm
VISO	*Viola sororia*	common blue violet	N	H	D	FFs59; FFs68; MHs39; MHs49	A/P	Apr-Jun	7-20 cm
VIRI	*Vitis riparia*	wild grape	N	C	D	FFs59; FFs68; MHs38; UPs24	P	May-Jun	10-22 m

Table 8 (Continued)

PS	Genus Species	Common Name	NS	P	G	H	LC	BS	PH
VUOC	*Vulpia octoflora*	six-weeks fescue	N	G	M		A	Mar -Jun	10-60 cm
WOBO	*Wolffia borealis*	spotted watermeal	N	F; H	M		P	Jul-Sep	1-30 cm
WOCO	*Wolffia columbiana*	Columbian watermeal	N	F; H	M		P	Jun-Sep	1.5 m m
WOIL	*Woodsia ilvensis*	rusty woodsia	N	H	F	ROs12	P	May - Aug	5-30 cm
WOOB 2	*Woodsia obtusa*	blunt-lobe cliff fern [WL]	N	H	F	CTs33	P	Jun-Oct	12-45 cm
XAST	*Xanthium strumarium*	cocklebur	N	H	D		A	Aug -Oct	20-150 cm
ZAPA	*Zannichellia palustris*	horned pondweed	N	H; S	M		P	Mar - Aug	1 m
ZAAM	*Zanthoxylum americanum*	prickly ash	N	D	D	FFs59; MHs38; MHs39; MHs49	P	Apr-May	4-6 m
ZIEL2	*Zigadenus elegans*	white camas	N	H	M	UPs23; WPs54	P	Jun-Aug	15-100 cm
ZIAP	*Zizia aptera*	heart-leaved alexanders	N	H	D	UPs13; UPs23; UPs24; WPs54	P	May	30-75 cm
ZIAU	*Zizia aurea*	golden alexanders	N	H	D	OOp93; WPs54	P	Apr-Aug	30-100 cm